Chapter 2

DESIGN, CONSTRUCTION, APPLICATION OF ENGINE COMPONENTS

By studying this chapter, you will learn to:

- Describe engine part design.
- Explain the construction of engine components.
- Define the purpose of each engine part.
- Identify engine part variations.

You have already designed and built an engine, on paper. To give you a clear idea of how the engine works, it was necessary to move from step to step without studying the finer points of engine construction.

Now that you are familiar with the general theory involved in engine design, it is desirable for you to study the parts of the basic engine in greater detail.

It is important for you to understand HOW the parts are built, of WHAT material, WHY they are built the way they are, and the PURPOSE each part serves.

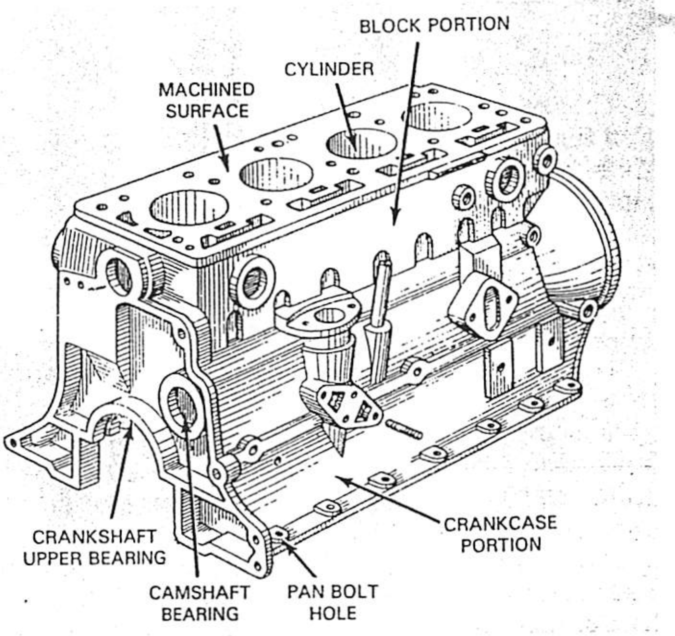


Fig. 2-1. Typical block construction for a four cylinder valve-in-head engine. (Nissan)

THE ENGINE BLOCK

The BLOCK, Fig. 2-1, serves as a rigid metal foundation for all parts of an engine. It contains the cylinders and supports the crankshaft and camshaft. In older engines, the valve seats, ports, and guides are built into the block. Accessory units and clutch housing are bolted to it. Note in Fig. 2-1 that the crankcase is formed with the block.

Blocks are made of either cast iron or aluminum. In some of the small, one cylinder engines, the material is die cast metal. Die cast metal is a relatively light, soft metal especially suited to the die casting process.

Blocks are commonly formed in two ways. One method is to pour molten cast iron, or aluminum, into a mold made of sand. A core is placed within the mold to form the cavities and passageways within the block. See Fig. 2-2. After the casting has cooled, it is removed from the mold, and the sand core is dissolved and washed out.

The second method is to use a mold of metal and force molten aluminum, or die-cast metal, into the mold under pressure. The pressure casting process has several advantages. It produces a block free of air

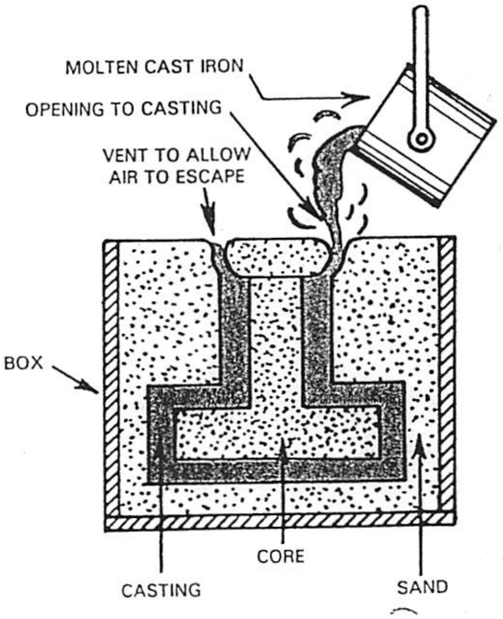


Fig. 2-2. Simple mold for casting.

bubbles (called voids), gives sharp corners, and a high degree of accuracy can be maintained. This reduces machining operations to a minimum. The same mold can be used over and over.

All parts of the aluminum or die cast block that are subjected to wear will have metal inserts either pressed in place or actually cast into the block.

The lighter the block (providing it has sufficient strength) the better. A more modern process, called PRECISION THIN WALL CASTING, controls core size and placement much more accurately than the older casting process. This permits casting the block walls much thinner, thereby effectively reducing the weight. Since wall thicknesses are more uniform, block distortion during service is less severe.

CYLINDERS

The cylinder is a round hole formed in the block. See Figs. 2-1 and 2-3. It is first cast into the block, then bored on a special machine and honed to a smooth finish. The cylinder dimensions must be kept extremely accurate. A good cylinder will not vary in diameter more than .0005 in. (0.013 mm). The paper on which this is printed is around .004 in. (0.102 mm) in thickness.

The cylinder forms a guide for the piston and acts as a container for taking in, compressing, firing, and exhausting the fuel charge. See Fig. 1-46.

Cylinders have been made of both steel and cast iron. Cast iron is by far the most popular. When steel cylinders are desired, they are in the form of cylinder sleeves (round, pipe-like liners). These sleeves may be either cast or pressed into the block.

Another manufacturing process die casts the block of aluminum that contains particles of silicon. After the cylinder is formed, an electro-chemical process is used to etch (eat) away the aluminum cylinder surface. This leaves the silicon exposed. The pistons are iron-plated aluminum and operate directly on the silicon surface of the aluminum cylinders.

CYLINDER SLEEVES

Some engines use removable cylinder sleeves. When the cylinder has become worn, the old sleeves may be pulled out and new ones pressed in. Fig. 2-4. The sleeves are pressed into oversize cylinder holes.

Cylinder sleeves are widely used in heavy-duty truck and industrial engines. If a cylinder wall is badly damaged, the old sleeve may be removed and a new one installed.

WET AND DRY SLEEVES

Cylinder sleeves are either wet type or dry type. The DRY SLEEVE, Fig. 2-5, is pressed into a hole in the block and is supported, and surrounded, over its full length. This type sleeve can be quite thin as it utilizes the block metal to give it full length support.

The WET SLEEVE, Fig. 2-6, is also pressed into a hole in the block. It is supported at the top and bottom only. The cooling water in the engine is allowed to directly contact the sleeve. The wet sleeve must be of heavier construction because it receives no central support from the block.

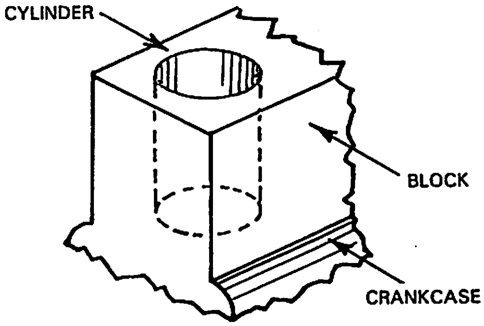


Fig. 2-3. Section of an engine showing cylinder location.

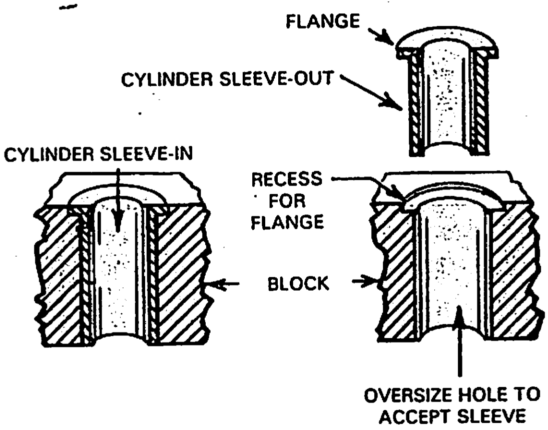


Fig. 2-4. Section of a block showing typical cylinder sleeve.

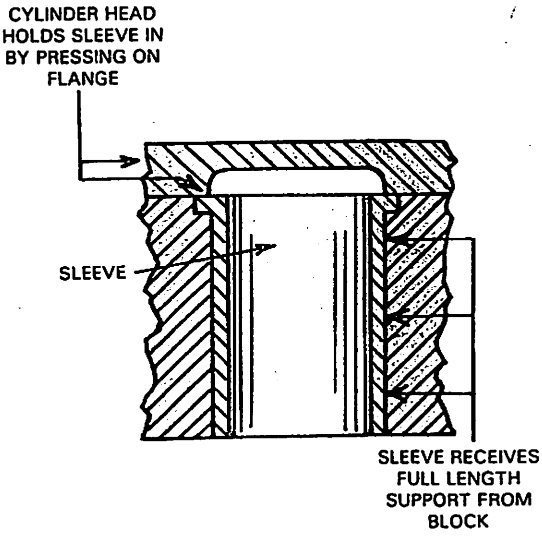


Fig. 2-5. "Dry" sleeve in place in cylinder hole.

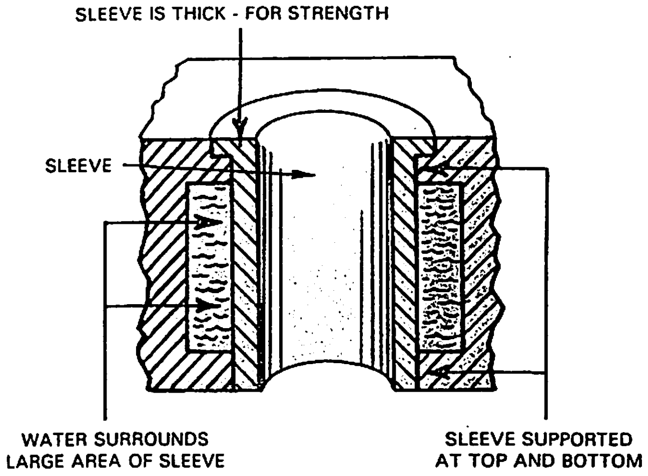


Fig. 2-6. "Wet" sleeve in place in cylinder hole.

SECURING THE SLEEVE

Sleeves can be secured in the block in several ways. Where a cast iron or steel sleeve is placed in an aluminum block to provide a wearing surface, it can be cast into place. See Fig. 2-7.

The removable sleeve may be held in place by friction alone, Fig. 2-8. However, this requires a very tight fit and is not altogether dependable.

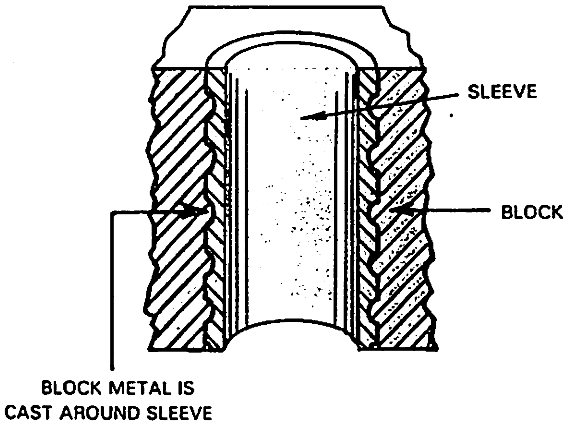


Fig. 2-7. Sleeve held by casting in block. Grooved sleeves prevent movement.

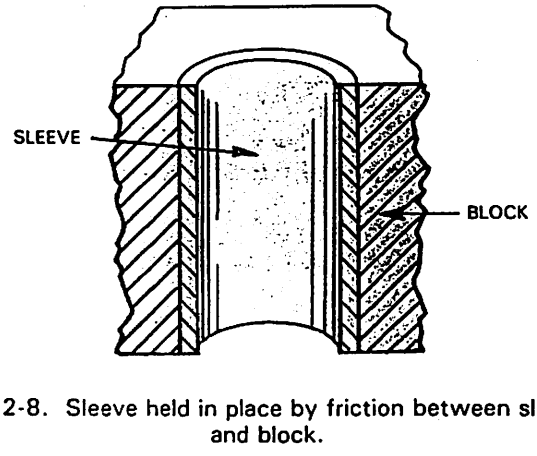


Fig. 2-8. Sleeve held in place by friction between sleeve and block.

A better method is to have a flange on the top edge of the cylinder sleeve that drops into a corresponding groove in the block. See Fig. 2-9. When the cylinder head is bolted on, it presses on the flange and holds it in place. This type of sleeve can be fitted with a greater degree of freedom. However, any sleeve must be a fairly snug fit so heat that is built up in the sleeve is conducted away by the surrounding block material.

PISTONS

The piston is literally a sliding plunger that rides up and down in the cylinder. It has several jobs to do in proper sequence. See Fig. 1-46.

The piston must move down through the cylinder to produce a vacuum to draw a fuel charge into the cylinder. It then travels up in the cylinder and compresses the mixture. When the mixture is fired, the pressure of the expanding gas is transmitted to the top of the piston. This drives the piston back down through the cylinder with great force, transmitting the energy of this firing stroke to the crankshaft. The piston then travels up through the cylinder, and exhausts the burned fuel charge.

Study the cross-sectional drawing of a piston in Fig. 2-10. Learn the names of all the parts of the piston.

The overall job the piston performs is a difficult one indeed. A piston is subjected to intense heat from the burning air-fuel mixture. It must change directions at "blurring speeds." It is "hounded" by friction against the cylinder walls. In addition to all this, the piston receives the tremendous thrust of power on the firing stroke. That a piston not only survives these forces, but will do so for many thousands of miles of driving, is a tribute to the engineering skill of engine manufacturers.

PISTON MATERIALS

Pistons are usually made of aluminum. Often, aluminum pistons are tin-plated to allow a good

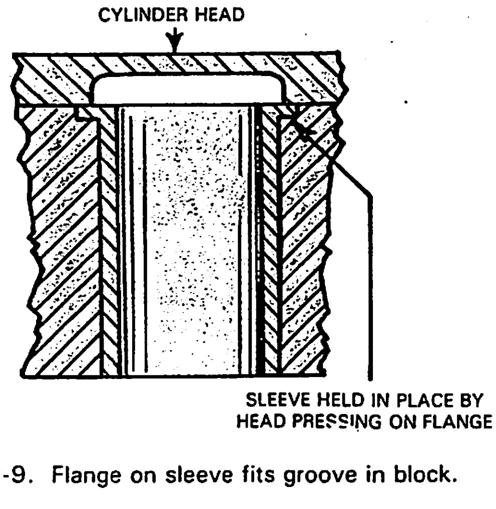


Fig. 2-9. Flange on sleeve fits groove in block.

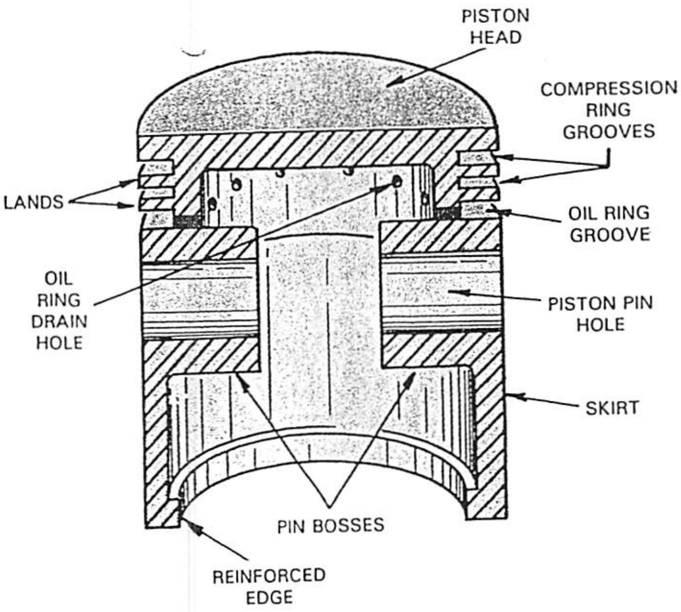


Fig. 2-10. Sectional view of a typical piston.

breaking-in job when the engine is started. Aluminum pistons can be forged, but are more commonly cast.

The aluminum piston is light and, for most purposes, this gives it an advantage over the cast iron type. A piston must change its direction of travel at the end of every stroke. At engine speeds sometimes in excess of 5000 revolutions per minute (rpm), it is obvious that the lighter the piston is, the more efficient it will be.

Cast iron is a good material for pistons used in a slow speed engine. It has excellent wear characteristics and will perform admirably in an engine suited to its needs. Pistons which are designed to operate in silicon aluminum cylinders are iron-plated aluminum.

EXPANSION PROBLEMS

Pistons must be carefully "fitted" into engine cylinders to prevent them from tipping from side to side ("slapping"). They must hold the burning fuel charges above the piston heads and be tight enough to form a vacuum and compress and exhaust burned gases.

A piston will expand when it gets hot, so enough clearance must be left between the piston skirt and cylinder wall to allow for this. Aluminum pistons expand more than cast iron, Fig. 2-11.

The problem of fitting the aluminum piston close enough to prevent "slapping," and still leave clearance enough for an oil film to separate the piston and the cylinder, has been solved in several ways.

SPLIT SKIRT

In a SPLIT SKIRT PISTON, Fig. 2-12, the skirt is either partially or, in some cases, completely split.

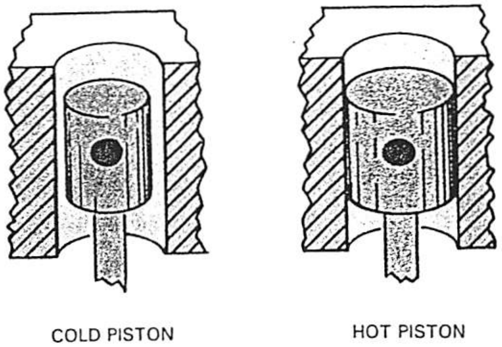


Fig. 2-11. Exaggerated view shows effect of heat on piston expansion.

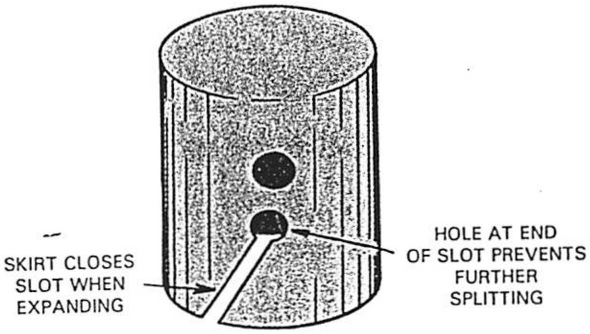


Fig. 2-12. Split skirt piston is designed to solve expansion problem.

When the piston warms and begins to expand, it cannot bind in the cylinder since the skirt merely closes the split.

T-SLOT

The T-SLOT PISTON, Fig. 2-13, is another variation of the split skirt. The top of the T tends to retard the transfer of heat from the head to the skirt of the piston. The vertical slot allows the skirt of the piston to close in when heated.

STEEL STRUT

Steel braces and in some cases, steel rings are cast into aluminum pistons. See Fig. 2-14. Steel expands less than aluminum and as a result, the steel struts tend to control or minimize piston expansion.

CAM GROUND

The CAM GROUND PISTON, Fig. 2-15, is a popular type. The piston, instead of being made round, is ground so that it is elliptical or egg shaped. Note in Fig. 2-15 that diameter A is larger than diameter B.

Diameter A is established so that the piston has a minimum amount of clearance in the cylinder. This clearance, around .001 in. (0.025 mm), is necessary to allow oil to form a lubrication film between the piston and cylinder wall. The larger diameter, at A, Fig. 2-15, is always at right angles to the block (in relation to the crankshaft center line).

As the piston heats up, it will not expand much in diameter A, but will tend to expand in diameter B. This will cause the piston to become round when fully heated. See Fig. 2-16.

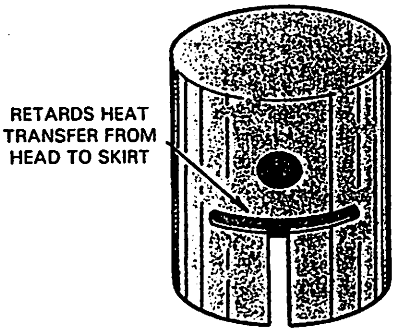


Fig. 2-13. T-slot piston is another means of controlling expansion.

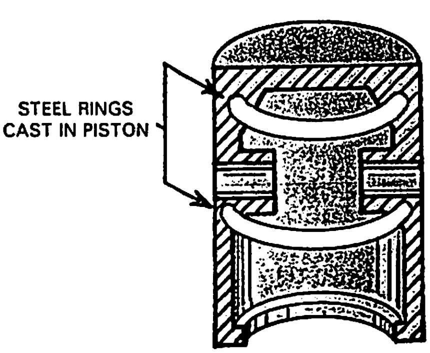


Fig. 2-14. Steel rings control or minimize piston expansion.

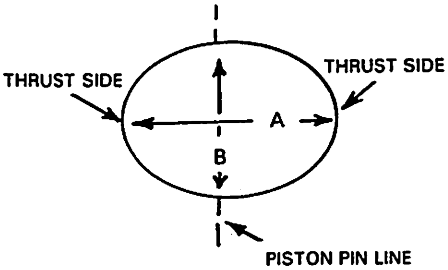


Fig. 2-15. Exaggerated top view of a cam ground piston, which is designed to be wider across the thrust surfaces.

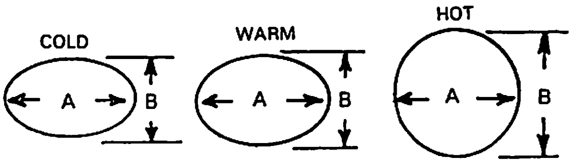


Fig. 2-16. Cam ground piston becomes round when hot. Diameter A remains constant; diameter B expands.

Cam grinding, then, will give a minimum clearance at the thrust surfaces. These are the two sides of the piston that contact the cylinder walls at right angles to the crankshaft. The thrust surfaces support the piston and prevent tipping. The thrust surfaces are also at right angles to the piston pin, Figs. 2-15 and 2-17.

PARTIAL SKIRT

In manufacturing PARTIAL SKIRT PISTONS, (also called slipper skirt), cam grinding is used but a large area of the skirt is removed. This reduces piston weight and allows the piston to approach the crankshaft more closely. Since the non-thrust sides of the skirts are removed, the counterbalances on the crankshaft, Fig. 2-18, will not strike the piston. Since

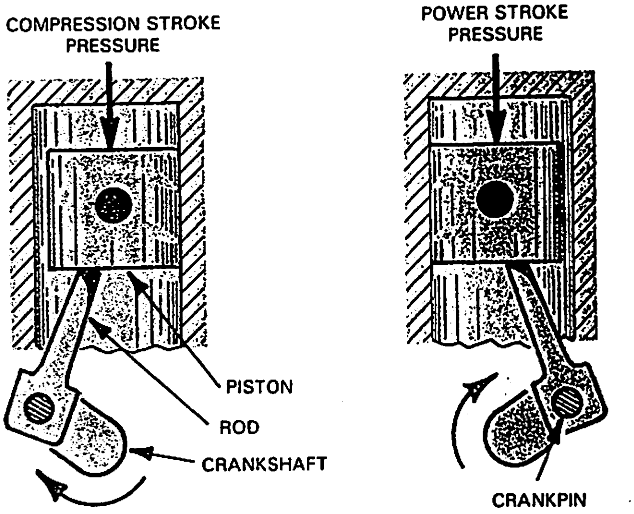


Fig. 2-17. Exaggerated view shows how a loose piston is pushed from one side of cylinder to other. Sides that rub cylinder wall are called thrust surfaces.

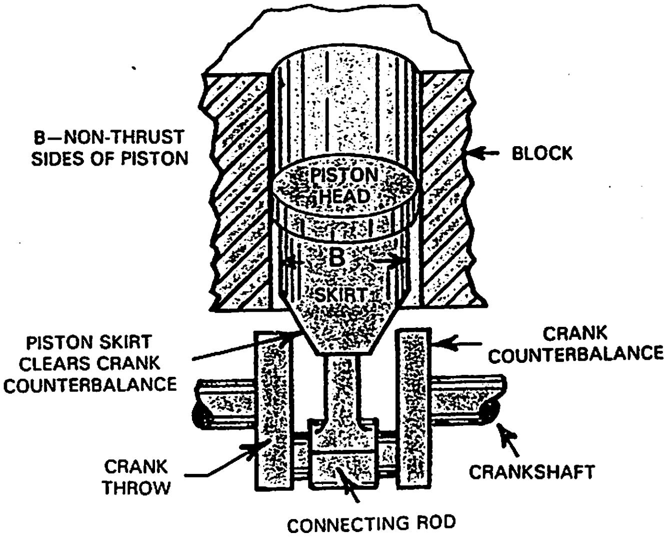


Fig. 2-18. Non-thrust sides of skirt are removed from partial skirt pistons. This allows piston to approach crankshaft more closely without striking.

the non-thrust sides of a piston do not carry much of a load, their removal is not detrimental.

PISTON TEMPERATURE

The piston head is subjected to the direct heat of the exploding fuel. This heat can raise the temperature of the piston crown (very top) somewhat above 600°F (316°C). The temperature will lower as you go down the piston. The bottom of the skirt will be about 300°F (149°C), Fig. 2-19.

The temperatures will vary according to engine design and work application. As the bottom of the skirt is the coolest, some pistons have the skirt slightly wider at the bottom. The top area of the skirt would be a trifle smaller in diameter.

HEAD CONSTRUCTION

It is obvious that the piston head is by far the hottest part of the piston. As a result, it expands more. In order to avoid having the head grow tight in the cylinder, the piston head is turned to a smaller diameter than the skirt of the piston (not cam ground). The head will generally be .030 to .040 in. (0.76 to 1.02 mm) smaller than the skirt. Fig. 2-20.

HEAD SHAPE

Some pistons have flat-topped heads. Others are dome shaped. Still others have irregular shapes designed to help in exhausting burned gases, and also to assist in creating a rapid swirling to help break up gasoline particles on the compression stroke. One type forms the shape of the combustion chamber in the head of the pistons, thus allowing the use of a flat surfaced cylinder head. Fig. 2-21.

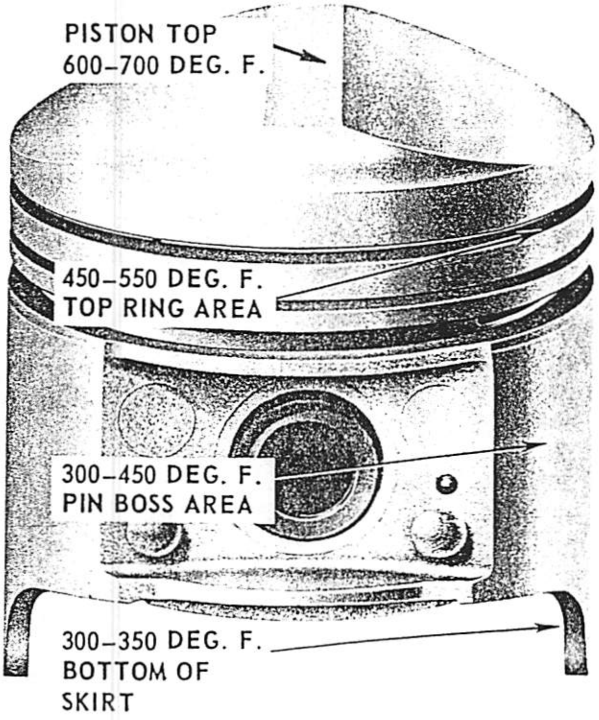


Fig. 2-19. Approximate temperature range is noted from piston head to skirt. Temperature can vary considerably depending on engine type, design, use, etc.

PISTON PIN BOSS

The section of the piston that supports the piston pin must be thicker and stronger. This area is called the PIN BOSS, as shown in Fig. 2-22.

THE PISTON CANNOT SEAL THE CYLINDER

The piston must have some clearance in the cylinder. If the skirt has .001 to .002 in. (0.025 to 0.05 mm) clearance and the head .030 to .040 in. (0.76 to 1.02 mm), it is obvious that the piston cannot seal the cylinder effectively. Fig. 2-23.

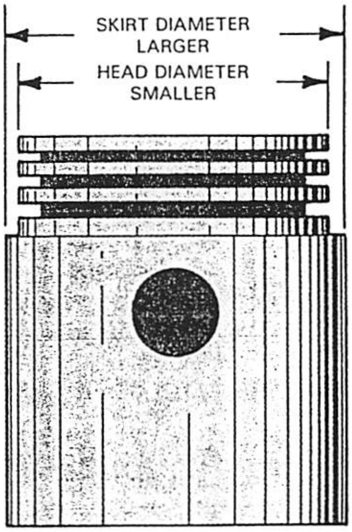


Fig. 2-20. As piston head is hottest part of piston, it must be ground approximately .030–.040 in. (0.76 to 1.02 mm) smaller than skirt.

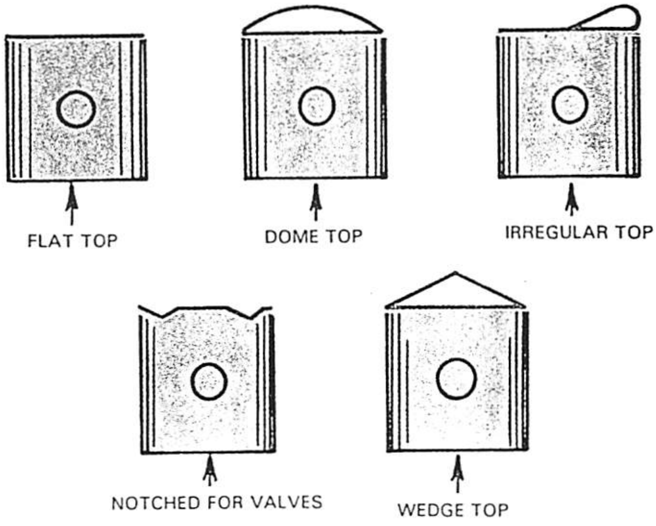


Fig. 2-21. Several types of piston heads.

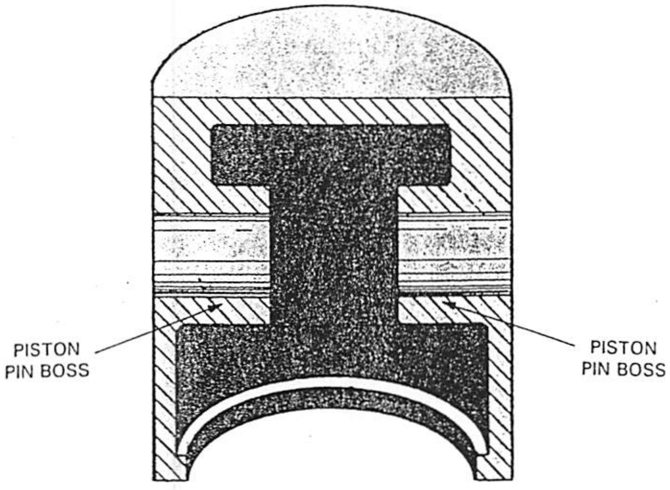


Fig. 2-22. Pin boss must be strong to withstand directional changes during each stroke of the piston.

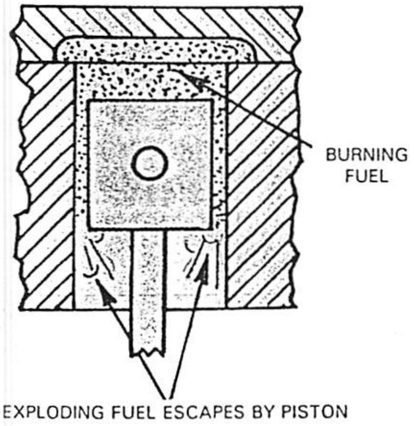


Fig. 2-23. Piston cannot seal by itself because clearance with cylinder wall must be maintained.

PISTON RINGS

The solution to the leakage problem is the use of PISTON RINGS. A properly constructed and fitted ring will rub against the cylinder wall with good contact all around the cylinder. The ring will ride in grooves that are cut into the piston head. The sides of the ring will fit the edges of the grooves quite closely. This side clearance can be around .002 in. (0.05 mm).

The rings will not contact the bottom of the ring grooves. Actually then, the ring will rub the cylinder wall at all times but will not be solidly fastened to the piston at any point. See Fig. 2-24.

RING GAP

The ring is built so it must be squeezed together to place it in the cylinder. This will cause the ring to exert an outward pressure, thus keeping it tightly against the cylinder wall. See Fig. 2-25.

The ring is not solid all the way around but is cut through in one spot. This cut spot forms what is called the RING GAP. Fig. 2-26.

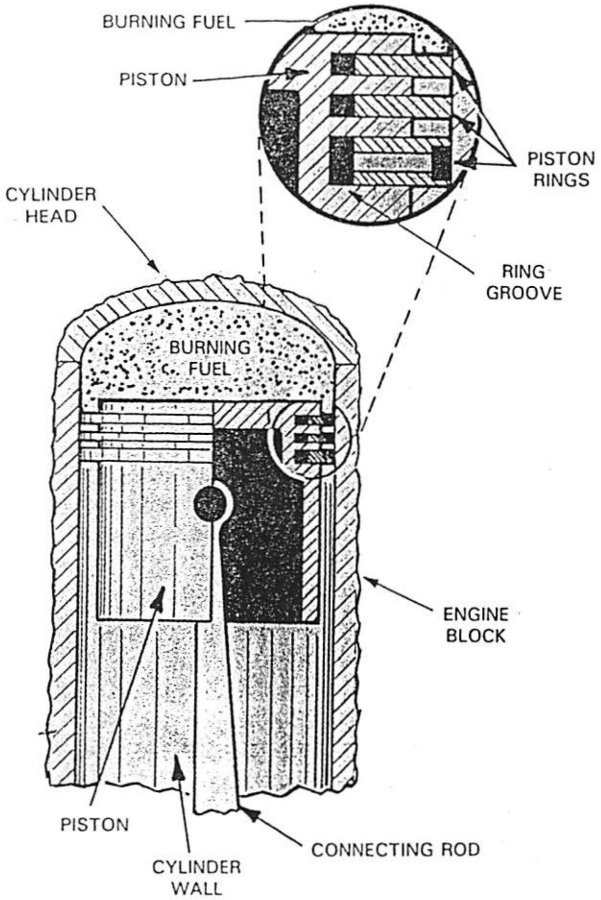


Fig. 2-24. Piston rings seal gap between piston and cylinder wall.

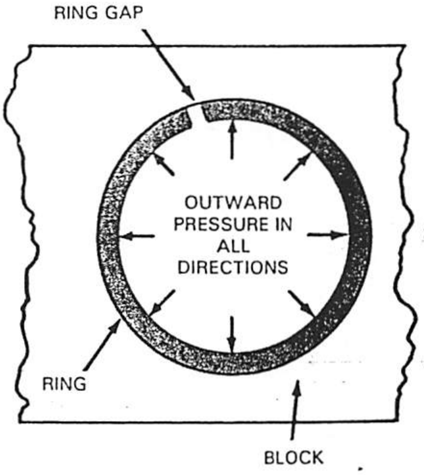


Fig. 2-25. Top view of cylinder shows sealing action of piston ring.

When the ring is in the cylinder, the cut ends must not touch. When the ring heats up, it will lengthen. Since it cannot expand outwardly, it will close the gap. If there is not enough gap clearance, the ends will soon touch and as the ring continues to lengthen, it will break up into several pieces. This can ruin a good engine.

A general rule for ring gap clearance is to allow .003 to .004 in. per inch (0.07 to 0.10 mm per 25.4 mm) of cylinder diameter. For example, a four inch cylinder would require from .012 to .016 in. clearance in the gap. Fig. 2-27.

Many different types of joints have been used in an endeavor to stop leakage through the ring gap. THIS LEAKAGE IS COMMONLY REFERRED TO AS BLOW-BY. It has been found that the common butt joint is about as effective as any and is much simpler to adjust. Fig. 2-28 illustrates a few of the types of joints that have been used.

The ring is placed in the groove by expanding it out until it will slip over the piston head and slide down and into the ring groove.

Fig. 2-29 illustrates how a compression type ring fits piston groove. Note that there is side as well as back clearance.

TYPES OF RINGS

There are two distinct types of rings. One is called a COMPRESSION RING and the other an OIL CONTROL RING.

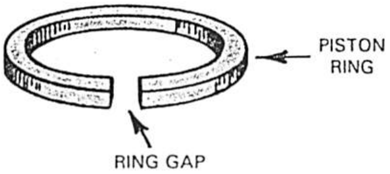


Fig. 2-26. Simplified piston ring showing ring gap.

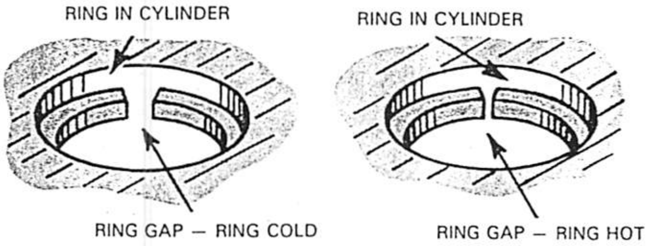


Fig. 2-27. Rings close gap when hot.

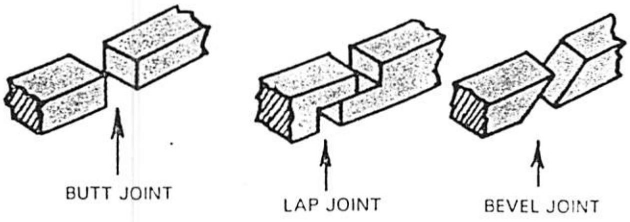


Fig. 2-28. Types of piston ring gap joints.

Most engines use three rings on each piston, two compression rings and one oil control ring. Others use two compression rings and two oil rings. Some diesel engines use five or more rings.

All rings may be above the piston pin; or a second oil control ring may be set into a groove near the bottom of the skirt. The compression rings are always used in the top grooves and the oil control rings in the lower grooves. Fig. 2-30.

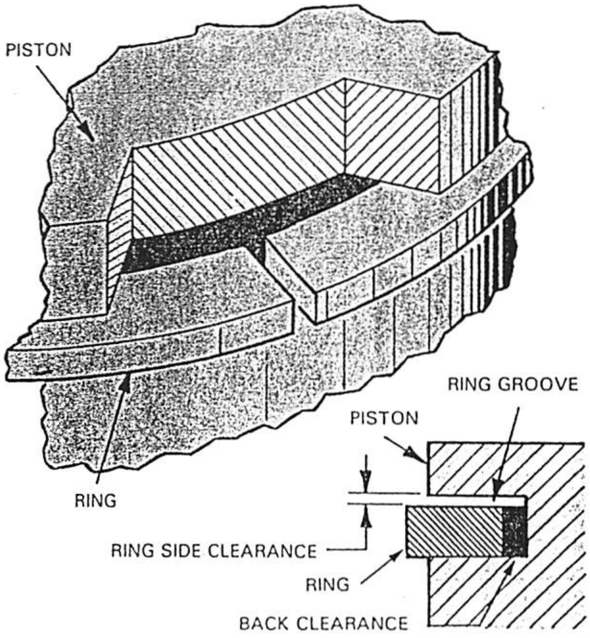


Fig. 2-29. Compression ring-to-groove fit. Note that ring has both side and back clearance. Side clearance is actually quite small, running around .0015 to .002 in. (0.04 to 0.05 mm).

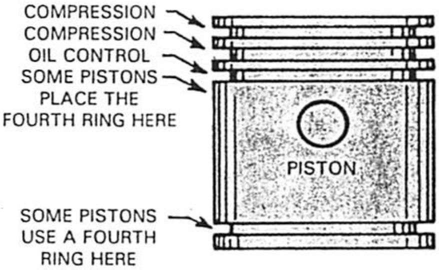


Fig. 2-30. Location of compression and oil control rings.

COMPRESSION RINGS

Compression rings are designed to prevent leakage between the piston and the cylinder. Fig. 2-31.

Various shapes are used to achieve this goal. Fig. 2-31. The idea behind the various grooves, bevels and chamfers is to create an internal stress within the ring. This stress will tend to force the ring to twist in such a fashion as to press the lower edge to the cylinder wall on the intake stroke. This will cause the ring to act as

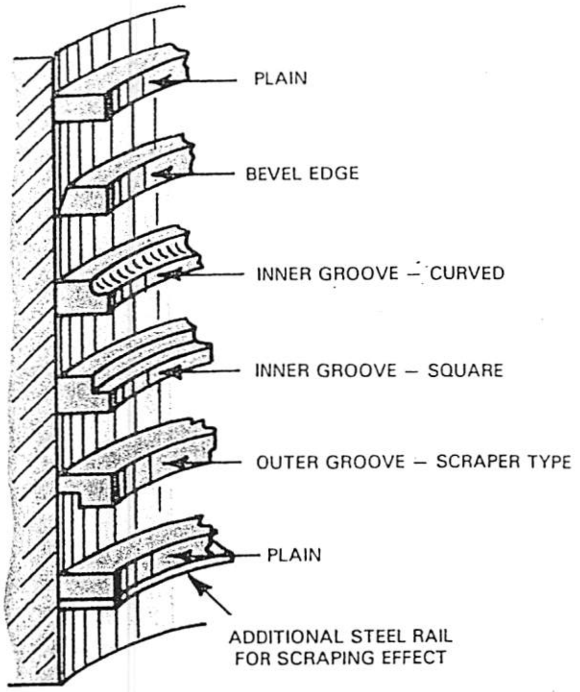


Fig. 2-31. Typical compression ring shapes, as they would look in a cylinder.

a mild scraper. The scraping effect will tend to assist in the removal of any surplus oil that may have escaped the oil control rings. Fig. 2-32.

On compression and exhaust strokes, the rings will tend to slip lightly over the oil film. This will prolong the life of the ring. Fig. 2-33.

On the firing stroke, pressure of the burning gases will force the top edges of the ring downward. This causes the ring to rub the wall with full face contact and to provide a good seal for the enormous pressure generated by the firing stroke. See Fig. 2-34.

HEAT DAM

The compression rings, especially the top ring, are subjected to intense heat. In an endeavor to minimize the transfer of heat from the head of the piston to the top ring, a HEAT DAM is sometimes used. This is actually a thin groove cut into the head of the piston between the top ring groove and the top of the piston. The heat, instead of passing through the aluminum of the piston to the ring, encounters the heat dam. This helps to minimize heat transfer. Fig. 2-35.

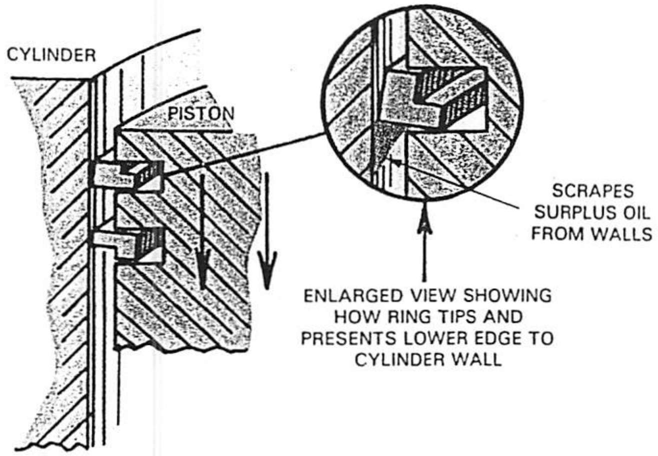


Fig. 2-32. Internal stress causes rings to tip and act as mild scrapers.

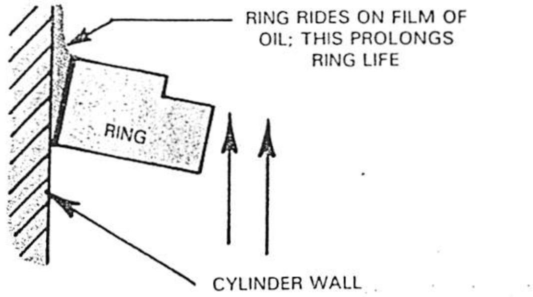


Fig. 2-33. On compression and exhaust strokes rings tip and slide easily on a film of oil.

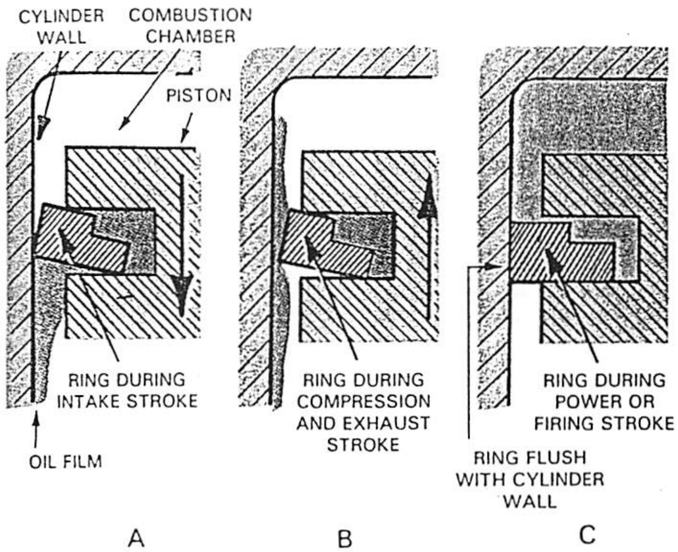


Fig. 2-34. Pressure of burning gases during firing stroke force ring down and out so that it is flush with wall.

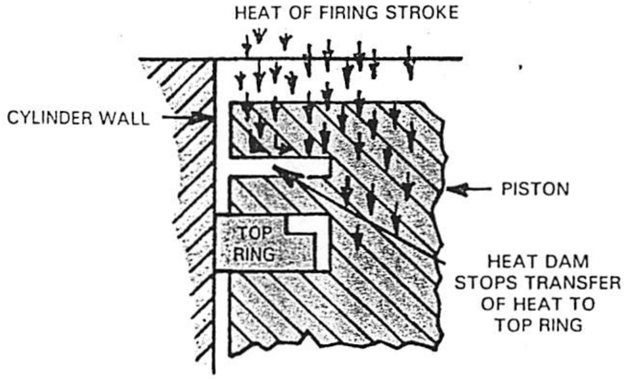


Fig. 2-35. Heat dam keeps top ring cooler.

TOP RING GROOVE INSERT

Some aluminum pistons have nickel-iron or comparable metal inserts cast into the piston heads. The top ring groove is cut in this metal. As top ring grooves in aluminum pistons pound out of shape, this insert groove will prolong the useful life of the piston and ring. Fig. 2-36.

OIL CONTROL RINGS

The oil control ring is used to scrape the surplus oil from the cylinder walls. This is not an easy task, and much time and money have gone into the design and construction of oil rings. Fig. 2-37.

All oil rings are slotted and have scraping edges designed to scrape the surplus oil from the cylinder walls. The oil between scrapers passes through slots in the ring on through slots or drilled holes in the bottom of the ring groove. From there the oil drips down into the crankcase area. Fig. 2-38.

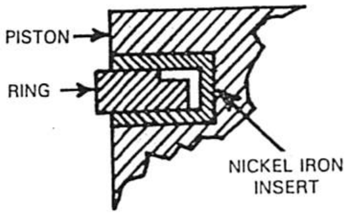


Fig. 2-36. Top ring insert groove, cast into piston.

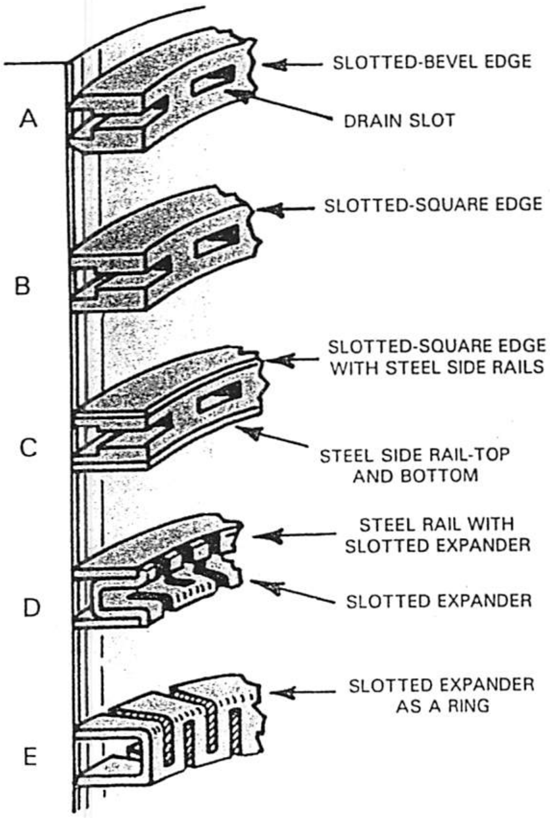


Fig. 2-37. Common types of oil control rings.

EXPANDER DEVICES

Some ring sets, especially those designed for worn cylinders, utilize expanding springs between the bottom of the ring groove and the ring. This will force the ring outward against the cylinder wall.

If a cylinder is worn, the top is invariably wider than the bottom. When the head of the piston is on the bottom of its stroke, the rings will be squeezed in the smaller section of the cylinder. Fig. 2-39.

When the piston travels up the cylinder, the rings must expand outward to follow the ever-widening cylinder diameter. Fig. 2-40.

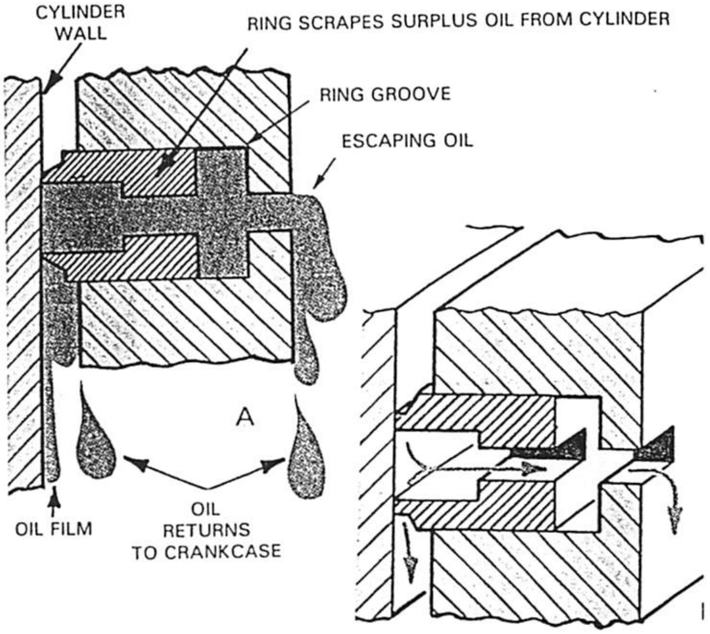


Fig. 2-38. A shows action of oil ring as it travels down cylinder. Note path oil takes in B.

This makes it necessary for the rings to expand, then contract, for every stroke. If engine speed is high enough, the piston will travel up the cylinder and will be snapped back down before the rings have time to expand. This leaves the piston at the top of the stroke with the rings not touching the cylinder walls.

Expander devices used for rings designed for worn cylinders are stronger than those used for a new or rebored cylinder. Fig. 2-41 illustrates a common type of ring expander.

Expanders are generally used under the oil ring, or rings, and the lower compression ring. The upper ring does not use one as the heat in this area would eventually destroy the temper in the expander spring.

Some expanders do not touch the bottom of the grooves. In this type, the ends butt together and when

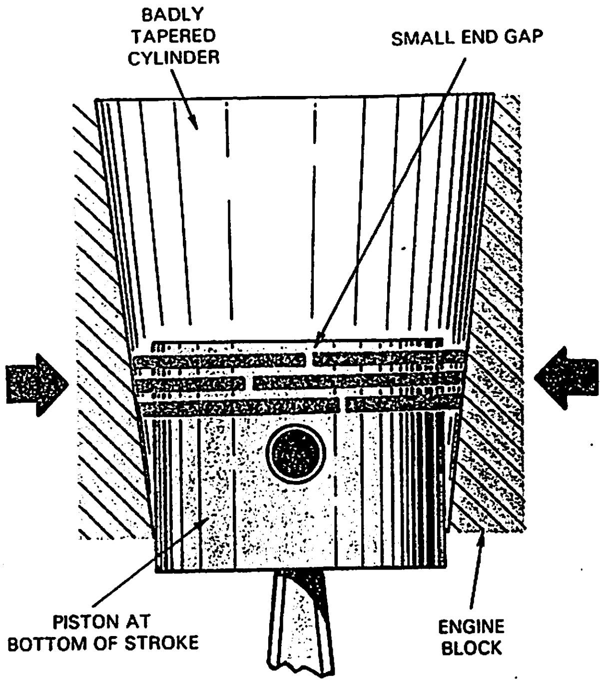


Fig. 2-39. Rings are compressed in bottom of cylinder.

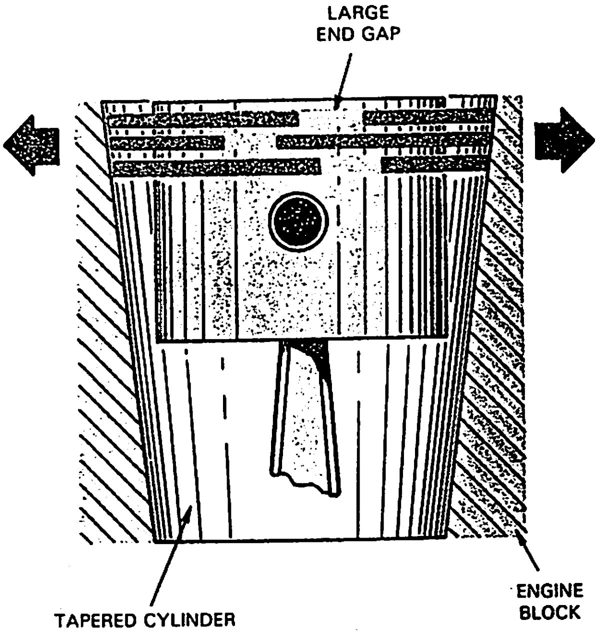


Fig. 2-40. Rings expand at top of cylinder. Note large end gaps.

closing up the ring to get it into the cylinder, the expander is compressed within itself. This type is illustrated in D, Fig. 2-37. Notice in E, Fig. 2-37, that the expander has been developed into a complete ring.

Another type of expander is a round wire spring type. The ends butt together, and even though the spring does not touch the bottom of the groove, it still pushes out on the ring, as shown in Fig. 2-42.

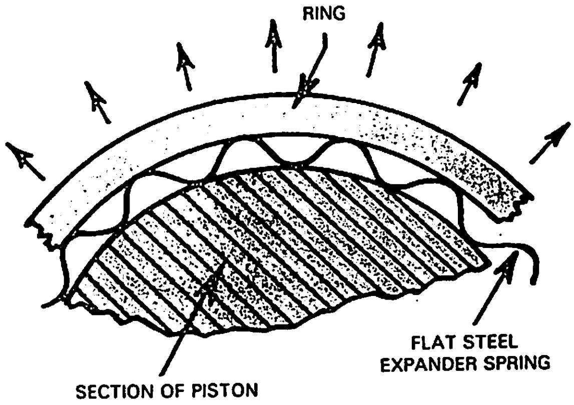


Fig. 2-41. Spring expander rests on bottom of ring groove and forces ring outward. This pressure will keep ring in constant contact with cylinder wall.

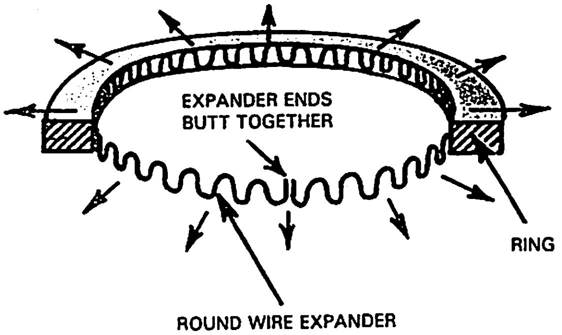


Fig. 2-42. Round wire spring expander does not touch bottom of ring groove. When ring is compressed to enter cylinder, spring is compressed within itself to keep constant tension on ring.

RINGS MUST FIT CYLINDER

In addition to following the cylinder walls, rings must make perfect contact all the way around. Fig. 2-43 illustrates a poorly fitted ring that would do a poor job of sealing.

Even with accurately bored cylinders, and new rings, it is impossible to secure a perfect fit when the rings are first installed. After the engine has operated for several hundred miles, the rings will wear into perfect contact with the cylinder walls.

WEAR-IN

To facilitate a fast job of wearing-in, the ring outer face is left rough. This surface feels smooth to the touch but a close inspection will show that fine grooves are left in the ring surface.

The cylinders may look smooth but final honing with fine stones leaves tiny surface scratches in the walls.

When the engine is started, the rings will be drawn up and down the cylinder. Since both the ring faces and the walls have fine scratches, this will cause some

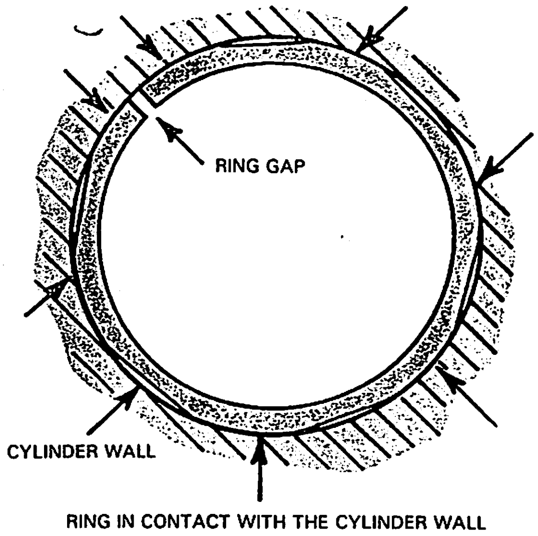


Fig. 2-43. Poor ring contact with cylinder wall is shown. Arrows indicate high spots that touch; area between does not touch.

wear. Any high spots on the ring faces will soon be worn off and the ring will fit properly. Fig. 2-44.

The ring and wall surfaces must be designed with a degree of roughness that will cause the rings to wear-in. As soon as a near perfect fit is achieved, the initial roughness will be gone and excessive wear will cease.

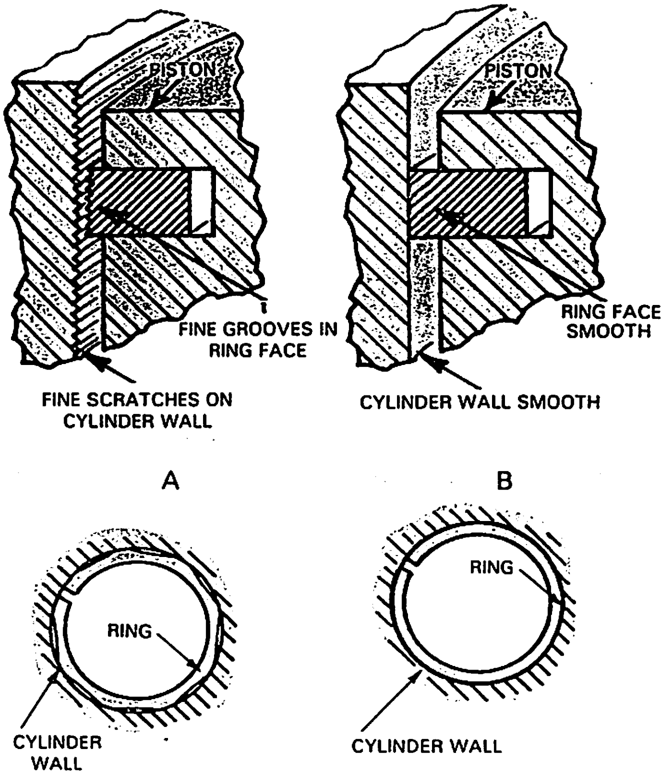


Fig. 2-44. Fine scratches in cylinder wall and grooves in ring face rub against each other to assist prompt wear-in. In detail A, ring touches cylinder only on high spots. Detail B shows ring contact after wear-in.

SPECIAL COATINGS

To assist with a fast wearing-in period, ring faces are often coated with a soft, porous material. Materials such as graphite, phosphate, and molybdenum are used for this purpose. See Fig. 2-45.

This soft, porous material also absorbs some oil and allows a gentle wear-in. Rings can also be tin coated.

All the expanding pressure of new rings is applied to the walls at the ring high spots. This can cause overheating and scuffing at these points. (Scuffing is a roughening of the cylinder wall. It is caused when there is no oil film separating the moving parts, and a hard metal-to-metal contact is made.) The porous coating wears quickly and, since it holds oil, the danger of scuffing is lessened.

Some rings have the outer edge chrome plated. This chrome surface will produce a ring that wears very well and stands up under severe operating conditions.

Chrome plated rings are generally finished somewhat smoother and to a higher degree of accuracy, giving less high points to retard wear-in. See Fig. 2-46.

RING MATERIAL

Piston rings are made from high quality cast iron having excellent wear properties. It also possesses a springy quality that will hold it out against the walls. The springiness of cast iron makes installation and handling a chore that must be done carefully to avoid breaking brittle rings.

Thin oil ring rails are made of steel. Some special expanding oil rings also utilize steel in their construction. Fig. 2-47. Some rings are made of stainless steel. Often, a molybdenum-filled cast iron ring is used in the top ring groove.

RING TYPES ARE NUMEROUS

Ring design is steadily improving. Many new designs are constantly appearing. All rings are designed to provide good sealing, long wear, quick

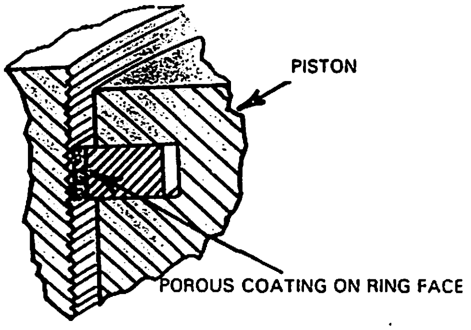


Fig. 2-45. Porous coating on ring face assures rapid and scuff-free break-in.

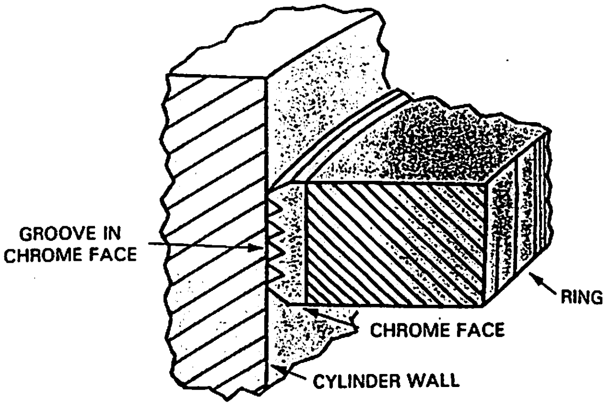


Fig. 2-46. Chrome face of chrome plated ring is grooved to aid break-in.

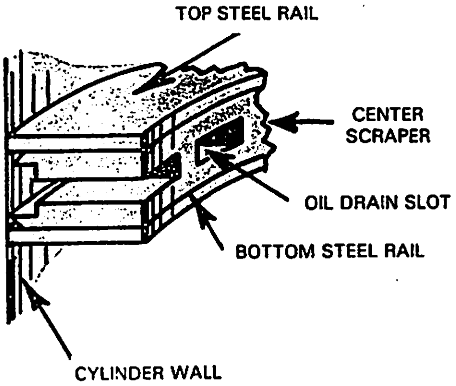


Fig. 2-47. Three-piece oil ring. Top and bottom rails are made of steel.

break-in, excellent oil control, and freedom from breakage.

PISTON PINS

Pistons are fastened to connecting rods by means of steel pins. These pins, called PISTON PINS, pass through one side of the piston, through the rod upper end, then on through the outer side of the piston. Look at Fig. 2-48.

The piston pin is usually hollow, to reduce weight. It is also casehardened to provide a long wearing surface. Casehardening is a process that hardens the surface of the steel but leaves the inner part fairly soft and tough to prevent brittleness. This hardness penetrates from .004 in. (0.10 mm) up to any depth desired. However, there would be little advantage in making the hard shell any deeper than a few thousandths of an inch. Fig. 2-49. Piston pins are ground to a very accurate size and are highly polished.

PIN INSTALLATION

Piston pins are installed and secured to provide a bearing action in three separate ways.

One way is to have the piston pin fastened to the rod and use the piston bosses for bearings. At times, bronze bushings are pressed into the bosses to provide bearing surfaces. Current practice favors a press fit (friction holds the two pieces together) between the piston pin and the connecting rod, with the pin oscillating in the aluminum pin bosses. See the illustration at right in Fig. 2-50.

Another method is to fasten the pin to one boss and let the rod oscillate on the pin. In this method, the upper connecting rod end must have a bronze bushing for a bearing surface. See Fig. 2-51.

The third method is to have the pin held in place at each end by a SNAP RING that rides in a shallow groove cut in the end of each pin boss. The pin is free to turn in the bosses or in the rod. This is called a free floating pin. Fig. 2-52.

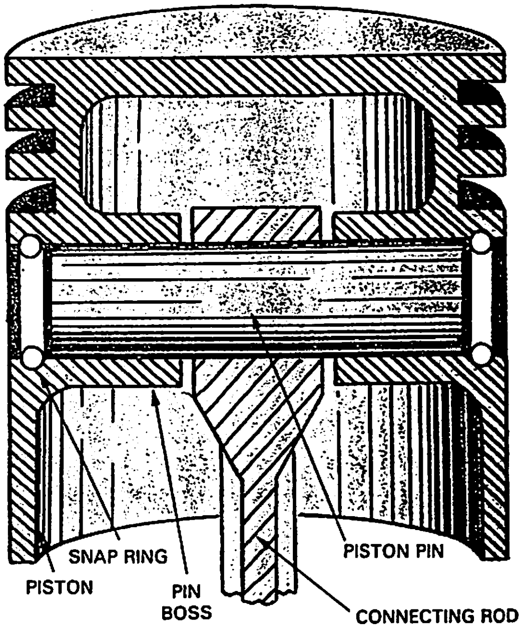


Fig. 2-48. Piston is fastened to the connecting rod with a piston pin.

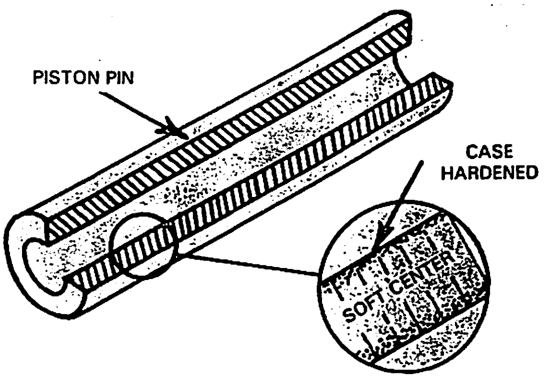


Fig. 2-49. Sectioned piston pin shows thin skin of casehardening.

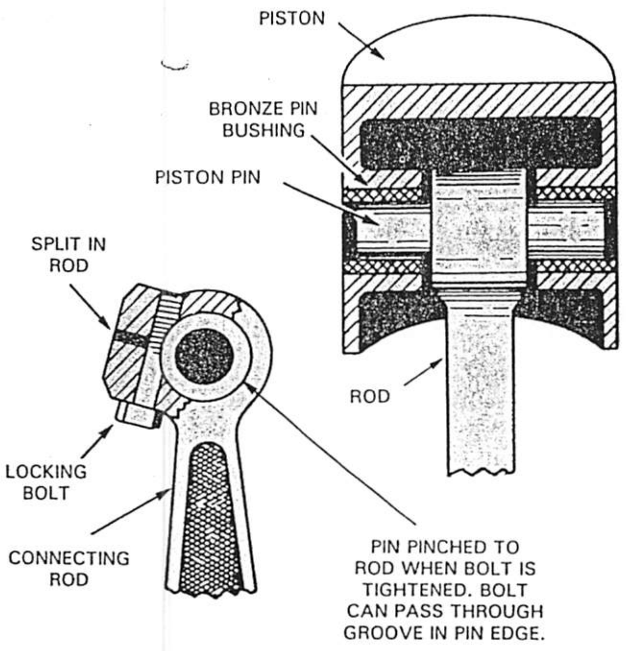


Fig. 2-50. Piston pin locked to rod turns in bronze bushings.

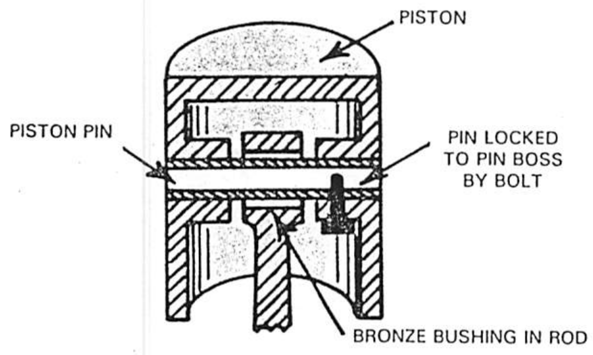


Fig. 2-51. Piston pin locked to one pin boss allows rod to oscillate on pin.

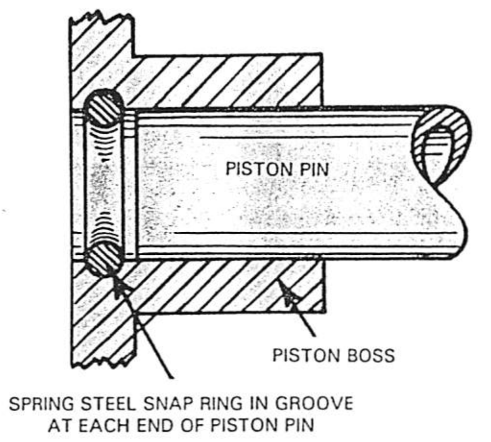


Fig. 2-52. Piston pin is free to turn in rod and in pin bosses. See Fig. 2-48 for full view.

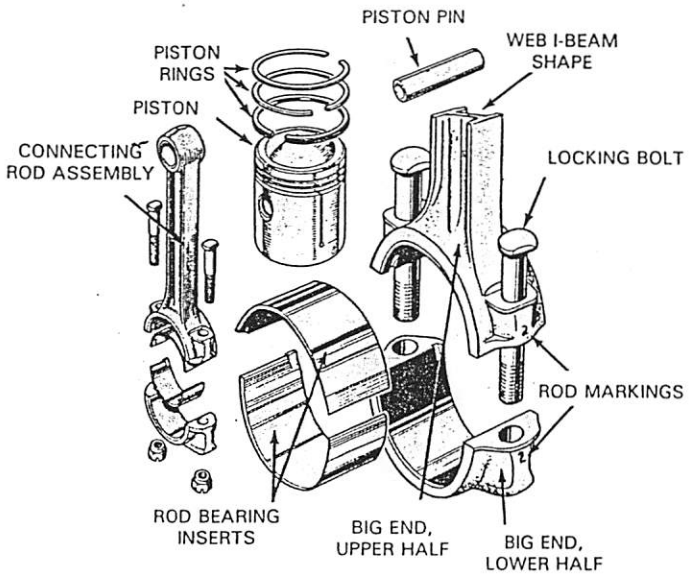


Fig. 2-53. Typical connecting rod; forged steel rod used in conjunction with aluminum piston. (Jaguar)

CONNECTING RODS

As the name implies, connecting rods are used to connect pistons to the crankshaft. Fig. 2-53.

The upper end of a rod oscillates (swings back and forth), while the lower or big end bearing rotates (turns).

As there is very little bearing movement in the upper end, the bearing area can be reasonably small. The lower (big) end rotates very fast, and the crankshaft journal turns inside the connecting rod. This rotational speed tends to produce heat and wear. To make the rod wear well, a larger bearing area is required.

The upper end of the rod has a hole through it for the piston pin. The lower end must be split so the rod can be installed on the crankshaft journal.

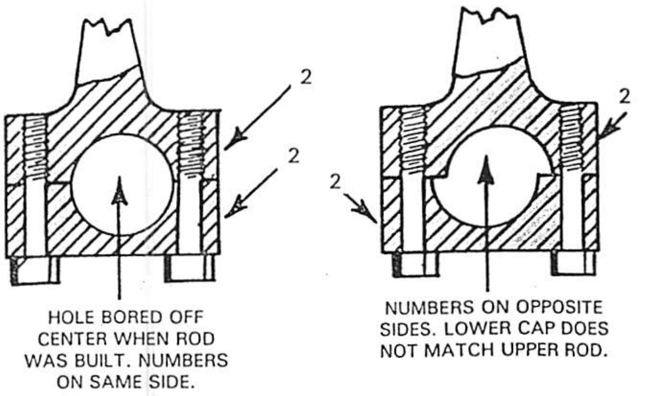
The upper and lower halves of the lower end of the rod are bolted together. The upper and lower halves should be numbered and when installed, the numbers should be on the same side. This prevents turning the cap around when installing the rod.

Turning the connecting rod cap around would make the rod bearing hole out-of-round. In making rods, the upper and lower halves are bolted together and the holes are bored to an accurate size. The hole may be slightly off-center. If the caps are crossed, the upper hole half may not line up with the lower hole. Fig. 2-54.

CONNECTING ROD CONSTRUCTION

Connecting rods are normally made of alloy steel. They are drop-forged to shape, then machined. The customary shape uses I-beam construction. Fig. 2-53.

Some rods are built of aluminum. Generally these are for small engines designed for light duty. Small engines often utilize the rod material for both upper and lower bearing surfaces. Special aluminum rods



HOLE BORED OFF CENTER WHEN ROD WAS BUILT. NUMBERS ON SAME SIDE.

NUMBERS ON OPPOSITE SIDES. LOWER CAP DOES NOT MATCH UPPER ROD.

Fig. 2-54. Numbers on rod and cap must be kept together.

for high speed, high performance engines can be purchased from specialty machine shops.

CONNECTING ROD BEARINGS

As mentioned, the upper end of the connecting rod may use a bronze bushing for a bearing surface. If the rod is bolted, or pressed to the piston pin, it will not use any special bearing. The bearings in this case would be in the piston boss holes.

The lower end uses what is termed a precision insert bearing. The rod bearing hole is bored larger than the crank journal and an INSERT BEARING is placed between the rod and journal. Fig. 2-55.

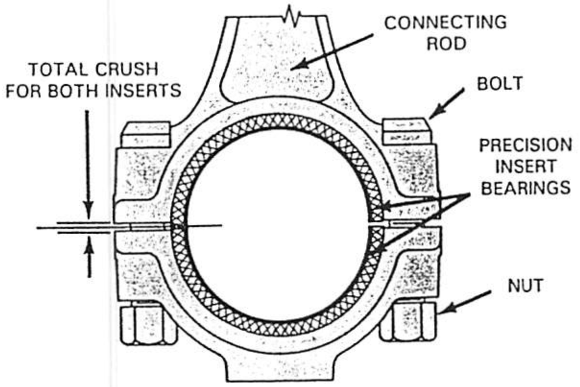


Fig. 2-55. Connecting rod precision insert bearing is properly fitted when bearing parting surfaces (ends) will touch before the rod halves meet. This provides crush. (Sunnen)

A bearing insert usually does not turn in the rod. It is held in place by a locating tab (locking lip) on the insert that is placed in a corresponding notch in the rod. Look at Figs. 2-53, 2-56, 2-57.

The insert must fit the rod snugly in order to transfer heat to connecting rod. To insure a proper fit, the insert will protrude a small amount above the rod bore parting surface. This distance (from less than .001 in. to .002 in. or less than 0.025 to 0.050 mm) is called CRUSH HEIGHT. When the rod halves are drawn together, the inserts touch before the halves, forcing the insert tightly into place. Fig. 2-55.

INSERT CONSTRUCTION

An insert is started as a steel shell. This gives it shape and rigidity. The inner part of the shell that contacts the journal, is then coated to form a lining.

Some bearings have steel shells with a thin (.002 – .005 in. or 0.05 – 0.13 mm) babbitt lining. Others use steel shells, then coat them with a copper-lead-tin matrix followed by a very thin (.001 in. or 0.025 mm) coating of pure tin. Others use aluminum coating. Fig. 2-57 illustrates a typical bearing insert.

BEARING CHARACTERISTICS

The ideal bearing is not easy to construct. For every advantage, there seems to be a disadvantage that goes with it. A good bearing must have many characteristics.

LOAD STRENGTH

The bearing is subjected to tremendous stress from the firing stroke. There is pounding as the crank first pushes up, then pulls down. The bearing must not become fatigued and crack, nor must it spread out from the pounding force.

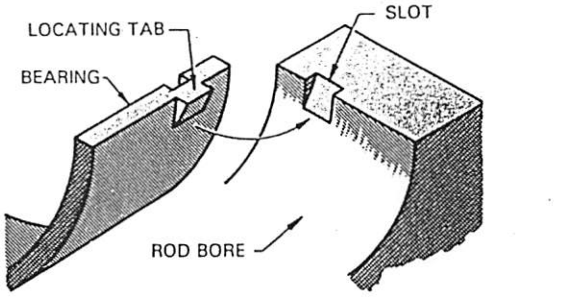


Fig. 2-56. Connecting rod precision insert is aligned and held in place by bearing locating tab engaging a slot in rod bore. (Clevite)

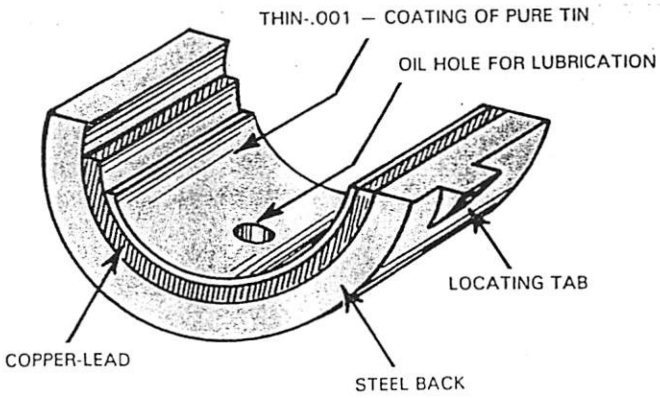


Fig. 2-57. Makeup of precision insert bearing is shown.

ANTISCUFFING

The material in the bearing should be such that in the event the oil surface skin is destroyed, the shaft journal will not be damaged by scuffing and scratching.

CORROSION

The bearing material must resist any tendency to corrode when exposed to vapors and acids in the crankcase.

CONFORMATION

No surface is perfectly true. Even with a highly accurate shaft, new rod, and insert, we cannot expect the bearing to fit the journal without some minute imperfection. A good bearing is soft and ductile enough to shape to the journal after it has been used for some time.

EMBEDABILITY

If a small abrasive particle enters the bearing area, the bearing should allow the particle to embed itself in the bearing material so it will not scratch the journal.

CONDUCTIVITY

All bearings produce heat. It is essential that the bearing material be of a type that will conduct heat to the rod. This is one reason why insert bearings must be a near-perfect fit.

TEMPERATURE CHANGE

The bearing strength must not be lessened when it reaches its operating temperature. It must have reasonable strength when both cold and hot. Fig. 2-58 illustrates various forces that work to destroy bearings.

Each insert must have a small hole to allow oil to enter for lubrication. Some inserts have shallow grooves in the surface to allow oil to spread out across the bearing. See Fig. 2-57.

CRANKSHAFT

The engine crankshaft provides a constant turning force to the wheels. It has throws to which connecting rods are attached, and its function is to change reciprocating motion of the piston to a rotary motion to drive the wheels. Crankshafts are made of alloy steel or cast iron. Fig. 2-59.

MAIN BEARINGS

The crankshaft is held in position by a series of main bearings. The maximum number of main bearings for a crankshaft is one more than the number of cylinders. It may have less main bearings than the number of cylinders.

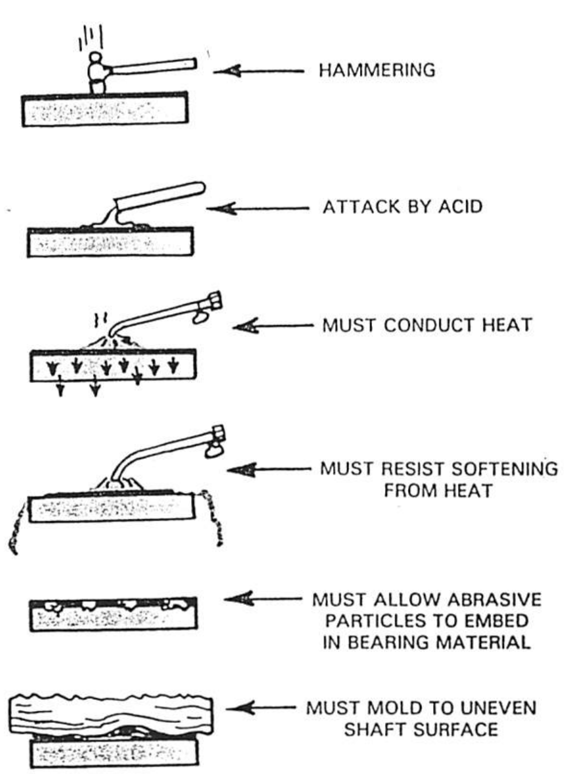


Fig. 2-58. Bearing inserts must resist many destructive forces.

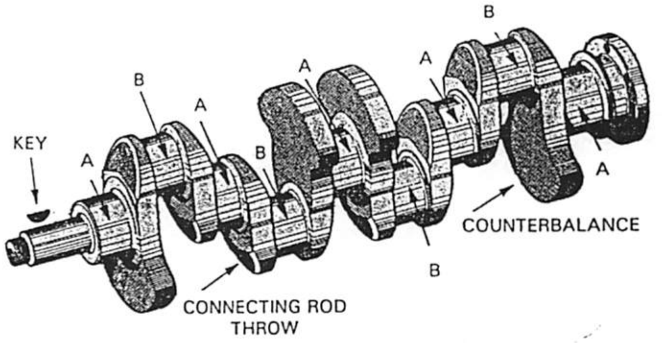


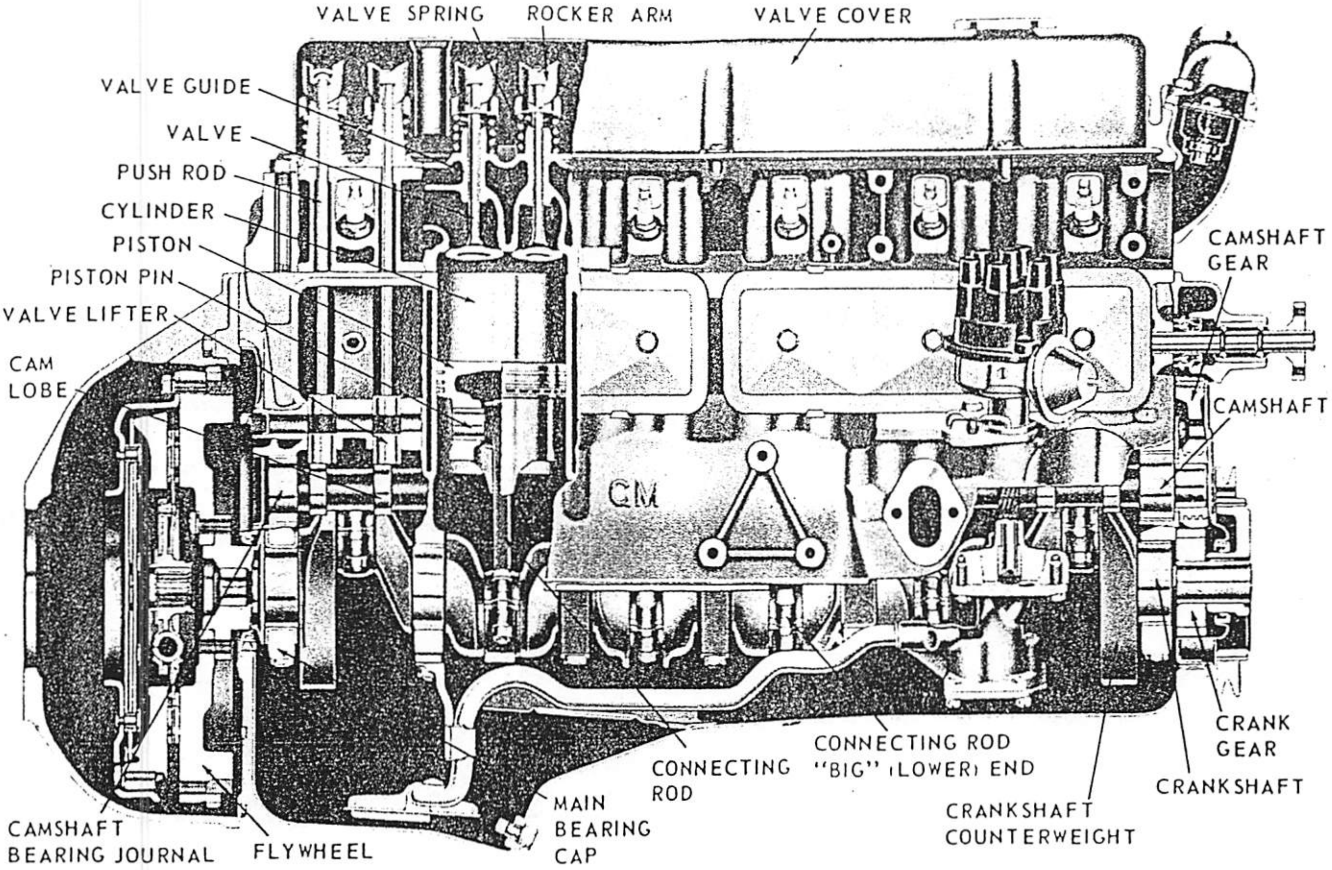
Fig. 2-59. Typical four cylinder engine crankshaft. A—Main bearing journals. B—Rod bearing journals. (Peugeot)

Most engines use precision insert bearings that are constructed like the connecting rod bearings, but somewhat larger. See Fig. 2-60.

In addition to supporting the crankshaft, one of the main bearings must control the forward and backward movement (end play) of the shaft. This bearing has flanges on the edges that rub against a ground surface on the edge of the crankshaft main journal. This bearing is referred to as a THRUST BEARING. Fig. 2-60.

CRANKSHAFT THROWS

The crankshaft throws (part of the shaft the connecting rod fastens to) must be arranged in such a way as to bring the piston to top dead center at the proper time for the firing stroke. As the pistons in a



Side view cutaway of a 6-cylinder, valve-in-head engine with 292 cu. in. displacement and a compression ratio of 8.01 to 1. Study the relationship of the various parts. (Chevrolet)

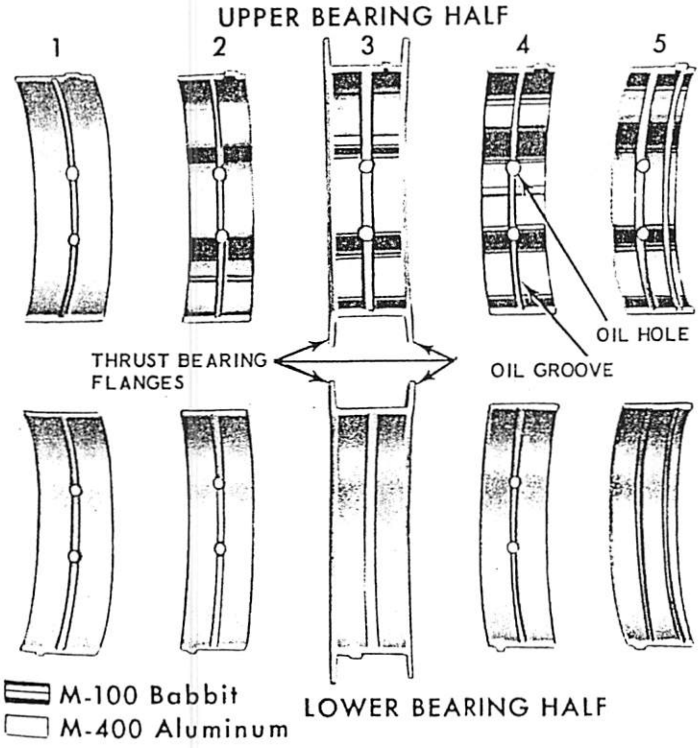


Fig. 2-60. Set of main bearings, some with an aluminum coating, others employ babbitt. Note thrust flanges on thrust bearing. (Cadillac)

multicylinder (more than one) engine do not fire one after the other, but fire in a staggered sequence, the throw position is very important. Fig. 2-61 illustrates an end view of four, six, and eight cylinder crankshafts. Illustrations A, C, D, and E are for in-line engines. An in-line engine is one in which all the cylinders are arranged one after the other in a straight row.

An eight cylinder in-line engine, Fig. 2-61D, requires eight connecting rod throws. A V-8 engine, B and F, has only four throws. Each throw services two connecting rods.

CRANK VIBRATION

To offset the unbalanced condition caused by off-center throws, many crankshafts use counterbalances to stop vibration. They may be forged as part of the crankshaft, or they may be bolted. Fig. 2-62.

VIBRATION DAMPER

When the front cylinders fire, power is transmitted through the rather long, crooked crankshaft. The pressure the piston applies can exceed 3,000 lbs. (1350 kg). The front of the crankshaft receiving this power tends to move before the rear, causing a twisting motion. When the torque is removed from the front, the

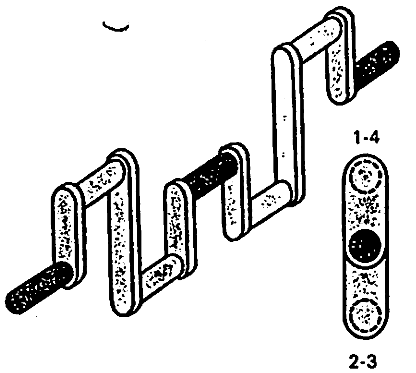


Fig. 2-61A. A four cylinder crankshaft will normally have throws spaced 180 deg. apart with cylinders 1 and 4 on the same side.

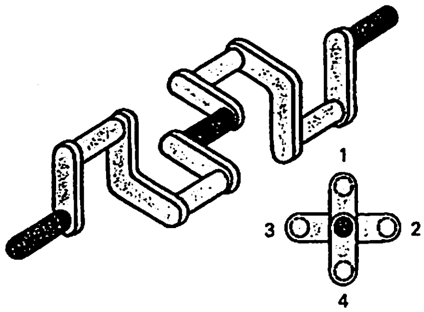


Fig. 2-61B. A V-8 engine may have the crankshaft throws arranged the same as a four cylinder engine, or method shown here which is widely used.

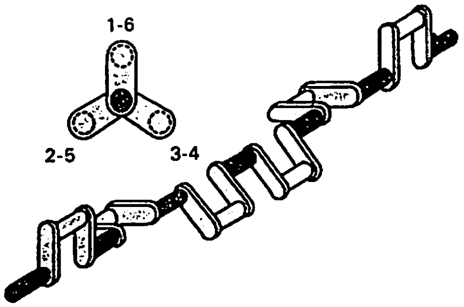


Fig. 2-61C. A right-hand crankshaft for a six cylinder engine will have throws arranged like this.

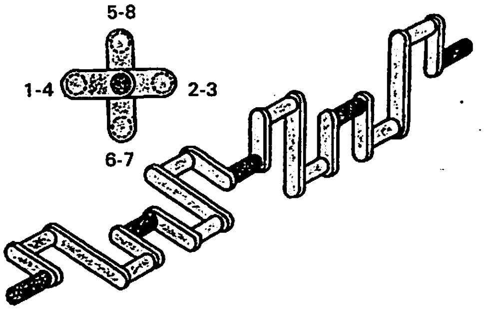


Fig. 2-61D. A straight eight crankshaft of 4-4 type resembles two four cylinder crankshafts connected end to end.

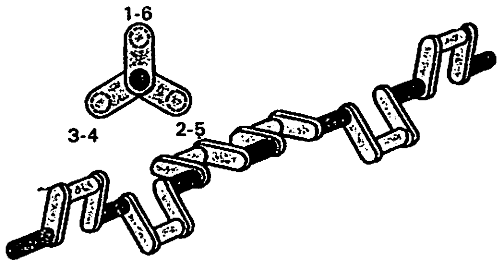


Fig. 2-61E. A left-hand crankshaft for a six cylinder engine will have No. 3 and 4 throws to the left of No. 1 and 6.

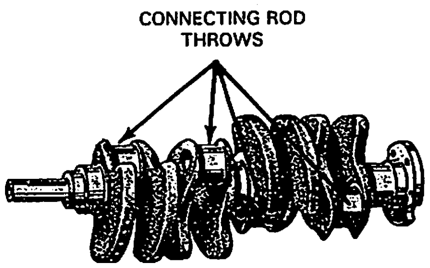


Fig. 2-61F. A typical V-8 engine crankshaft has same arrangement of connecting rod throws as shown in Fig. 2-61B. (Ford)

partially twisted shaft will unwind and snap back in the other direction. This unwinding, although minute, causes what is known as torsional vibration.

To stop the winding motion, a vibration damper, sometimes called a HARMONIC BALANCER, is attached to the front of the crankshaft. Basically the damper is built in two pieces. These pieces may be connected by rubber plugs, or spring loaded friction discs, or a combination of the two. Fig. 2-63.

When a front cylinder fires and the shaft tries to speed up, it tries to spin the heavy section of the damper. In doing this, the rubber connecting the two parts of the damper is twisted. The shaft does not speed up as much with the damper attached.

The force necessary to twist the rubber and to speed up the heavy damper wheel, tends to smooth out the crankshaft operation.

When the firing pressure is removed from the shaft, the shaft cannot spring back quickly because the twisted rubber attempts to keep the damper wheel turning. The unwinding force of the crankshaft cancels out the twist in the opposite direction.

DRILLED, GROUND AND POLISHED

The crankshaft is drilled so oil being fed to the main bearings will pass through the shaft to the connecting rod throws.

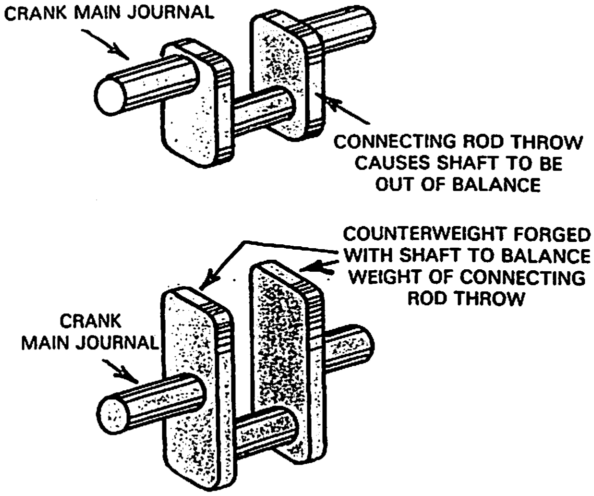


Fig. 2-62. Crankshaft needs counterweights to bring shaft into proper balance.

All bearing surfaces are precision ground and are highly polished. Fig. 2-64.

TIMING GEAR OR SPROCKET

A timing gear or a chain sprocket is installed on the front end of the crankshaft. A chain sprocket is usually made of steel. In the case of the timing gear, the teeth are helical in shape.

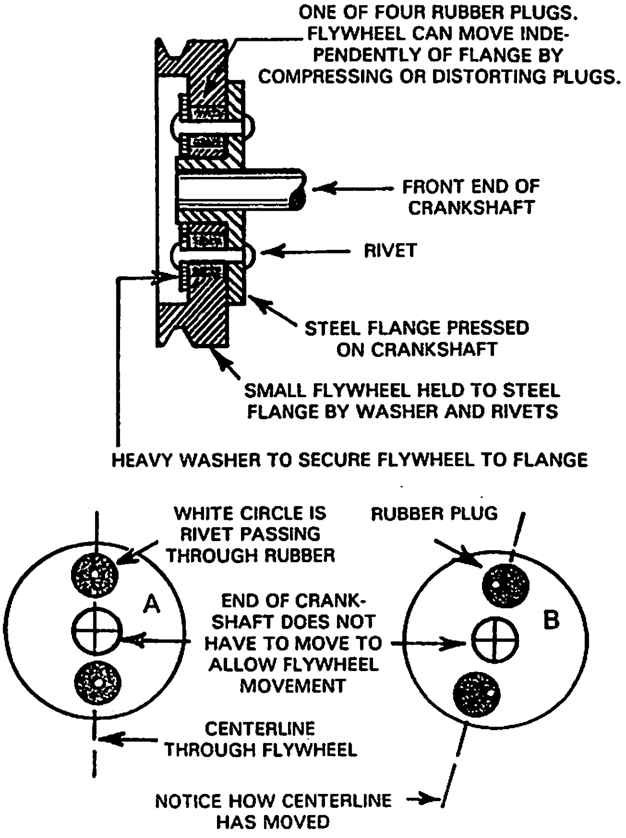


Fig. 2-63. Vibration damper utilizes small flywheel which moves a limited amount, bending rubber plugs. See A and B.

A timing gear is used to turn a camshaft timing gear. Where a sprocket is used, the sprocket will drive a timing chain that operates the camshaft by means of a larger sprocket. Fig. 2-65.

A timing gear or sprocket is secured to the crankshaft by means of a metal key that rides in a slot

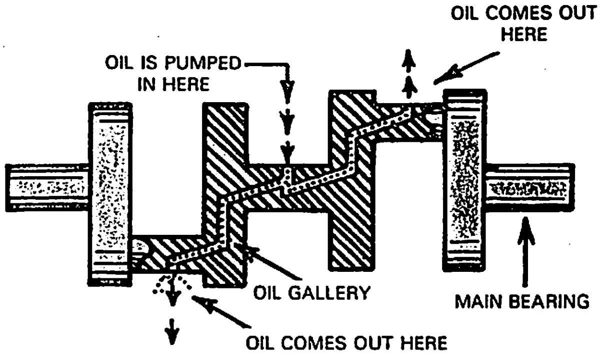


Fig. 2-64. Crankshaft partially cut away shows how oil is pumped into center main bearing. From there it enters an oil gallery drilled through the crankshaft to each rod journal.

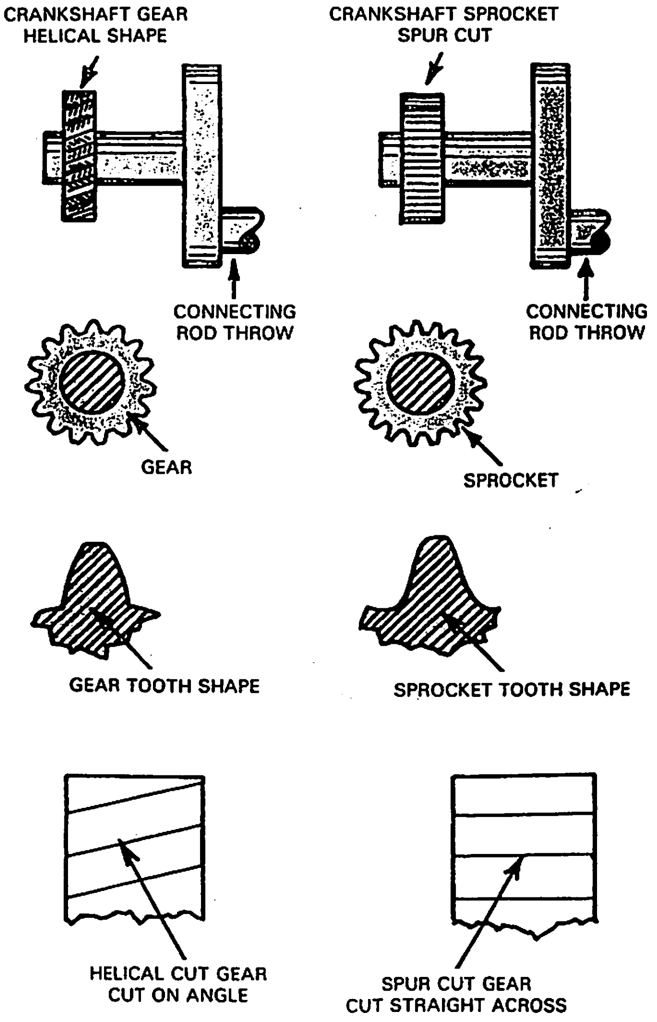


Fig. 2-65. Timing gear drive gear on crankshaft; also timing chain (or belt) drive sprocket on crankshaft.

cut in the crankshaft. The gear or sprocket also has a slot or groove in it. Fig. 2-66.

FLYWHEEL

A heavy flywheel is attached to the rear end of the crankshaft by means of bolts. The function of the flywheel is to smooth out engine speed and keep the crankshaft spinning between power strokes.

In some engines the flywheel also serves as a mounting surface for the clutch. See Fig. 2-67.

The outer rim of the flywheel has a large ring attached with gear teeth cut into it. The teeth of the starter motor engage this gear and spin the flywheel to crank the engine. When an automatic transmission is used, the torque converter assembly acts as a flywheel.

CAMSHAFT

An engine camshaft is used to open and close the valves. There is one cam on the camshaft for each valve in the engine. Generally only one camshaft is used in each engine. (On the elementary engine you designed in Chapter 1, you used two camshafts and the valves were arranged in a T-fashion to better illustrate the action in relation to an end view of the crankshaft.) A camshaft has a series of support bearings along its length.

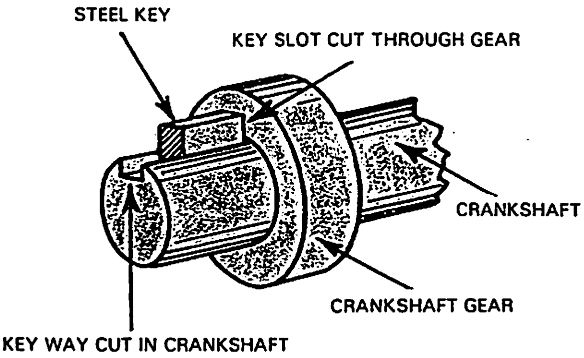


Fig. 2-66. A steel key, sliding in a slot in the crankshaft, passes through a similar slot in the gear to secure the gear to the shaft.

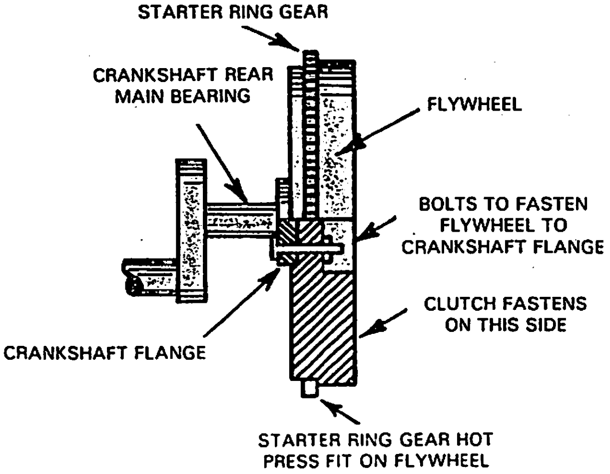


Fig. 2-67. Heavy flywheel is bolted to the crankshaft flange.

Camshafts turn at one-half crankshaft speed.

The cam lobes are usually not flat across the top as they might appear. The bottom of the valve lifter may be slightly crowned and the cam lobe tapered. This places the lobe-to-lifter contact to one side of center. Fig. 2-68.

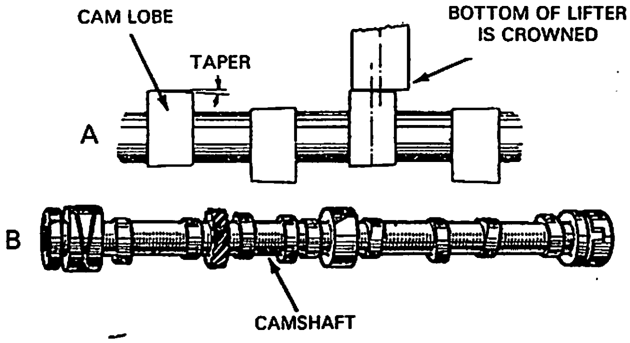


Fig. 2-68. A—Section of camshaft showing one method of tapering cam lobes. Lifter bottom is crowned. B—Typical camshaft design.

A gear cut into the camshaft is used to drive the distributor and oil pump.

The camshaft is kept in place by using a thrust washer behind the timing gear bolted to the block. Or, a spring loaded plunger is used to push on the end of the camshaft. An additional cam may be ground on the shaft to drive the fuel pump.

The typical camshaft is made of cast, or forged, steel. The cam surfaces are hardened for long life. Fig. 2-69 illustrates a typical camshaft with gear and thrust washer. The camshaft may be turned by a gear, timing chain, or a toothed timing belt. Figs. 2-70, 2-71, 2-72.

The camshaft gear can be made of cast steel, aluminum or a special pressed fiber. Chain sprockets are made of cast steel.

VALVES

Each engine cylinder ordinarily has two valves. However, some special racing engines use four valves per cylinder.

Exhaust valves are made of heat resistant metal, because the head of a valve operates at temperatures up to 1300°F (704°C). It is obvious that the steel used in valve construction must be of high quality.

In order to prevent burning, the valve must give off heat to the valve guide and to the valve seat. The valve must make good contact with the seat, and must run with minimum clearance in the guide.

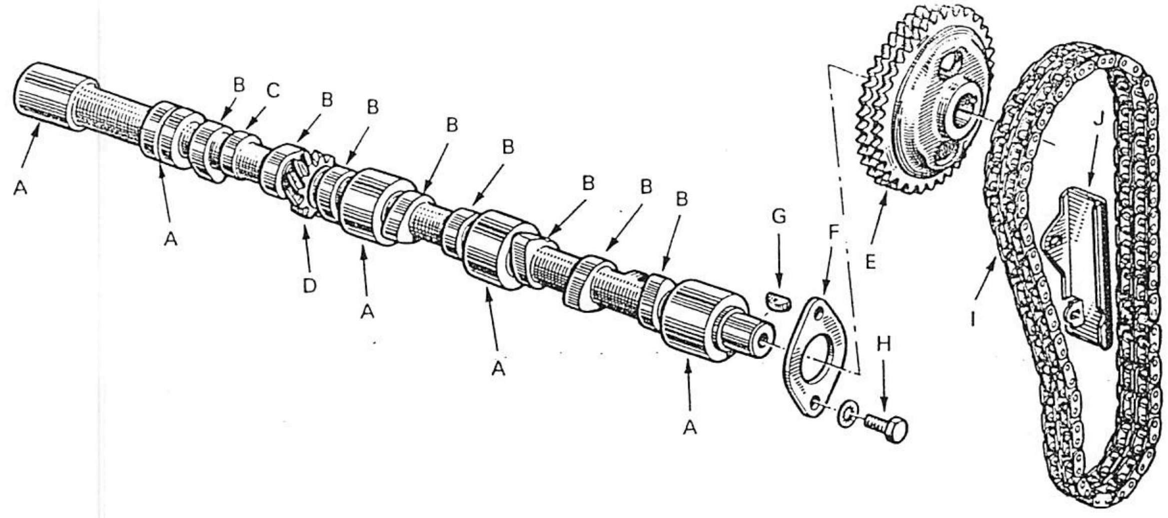


Fig. 2-69. Typical camshaft. A—Main camshaft bearings. B—Cam lobes. C—Eccentric to drive fuel pump. D—Gear to drive distributor. E—Camshaft sprocket. F—Thrust washer. G—Key. H—Retaining capscrew. I—Timing chain. J—Rubbing block. (Renault)

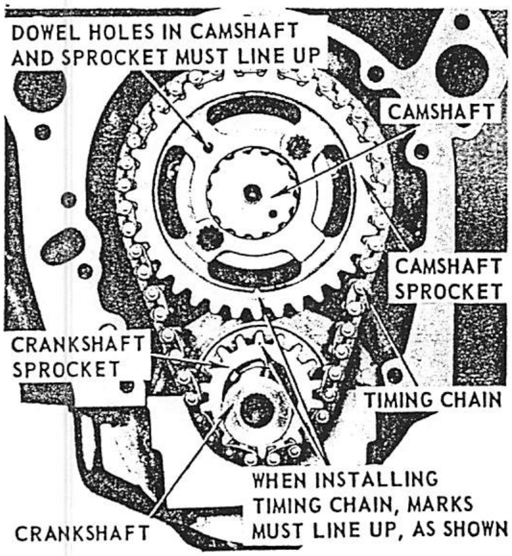


Fig. 2-70. Front view of typical timing chain drive. Shows alignment of valve timing marks. (Cadillac)

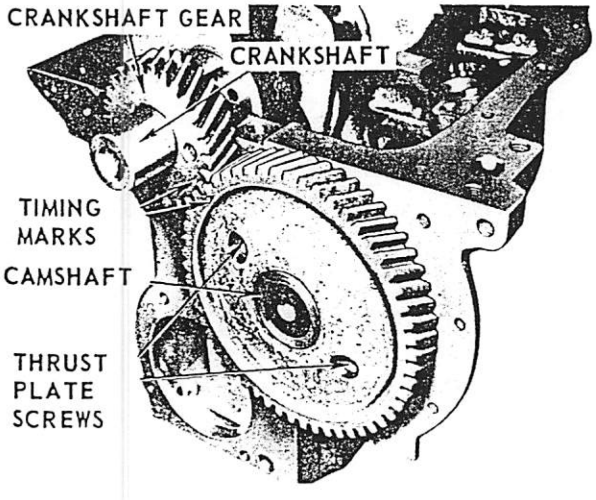


Fig. 2-71. Timing gear drive for camshaft also requires alignment of timing marks. (Chevrolet)

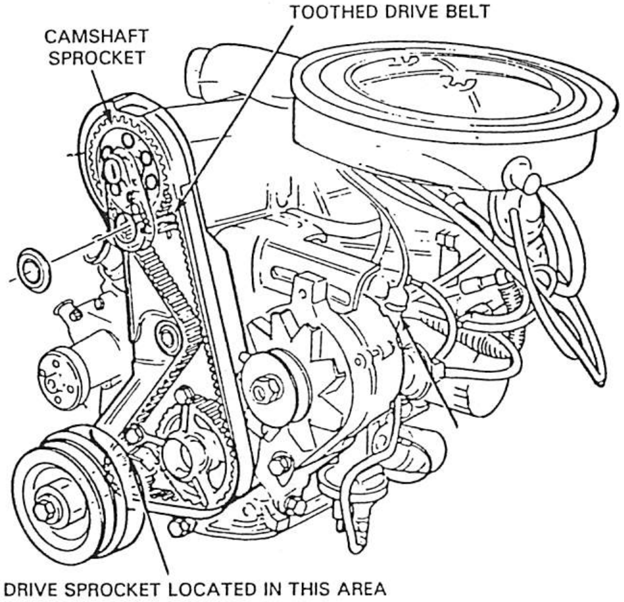


Fig. 2-72. Overhead camshaft driven by a toothed drive belt. (Ford)

Some valves have special hardfacing on the face areas to increase their useful life. Others use hollow stems filled with metallic sodium. Fig. 2-73. At operating temperature, the sodium becomes a liquid and splashes up into the head. This draws the heat into the stem where it transfers to the valve guide.

VALVE SEATS

Two angles commonly used for valve seats are 30 and 45 deg. Some makers grind a one degree difference between the valve face and seat to permit fast seating. Fig. 2-74. The seat may be ground to 45 deg. and the valve, 44 deg., or vice versa (the other way around).

Valve seats can be cut in the cylinder head, or special, hard steel inserts may be pressed into the

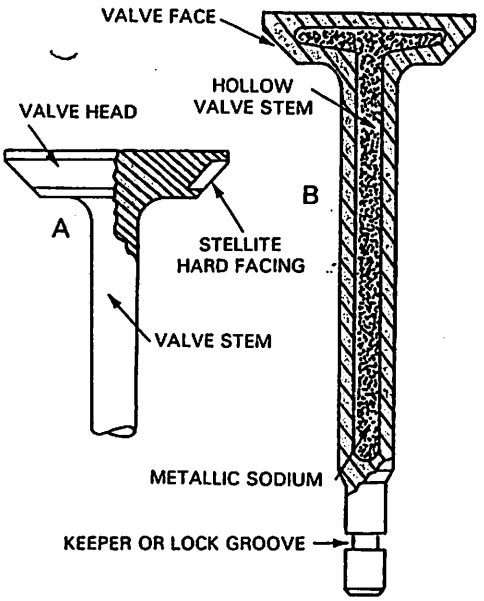


Fig. 2-73. A–Valve with special hard facing to lengthen useful life. B–Special heat resistant valve utilizing a hollow stem partially filled with metallic sodium.

DANGER–The sodium inside the valve is dangerous! Never drill, cut, etc., into such a valve. If worn out, dispose of carefully as recommended by manufacturer!

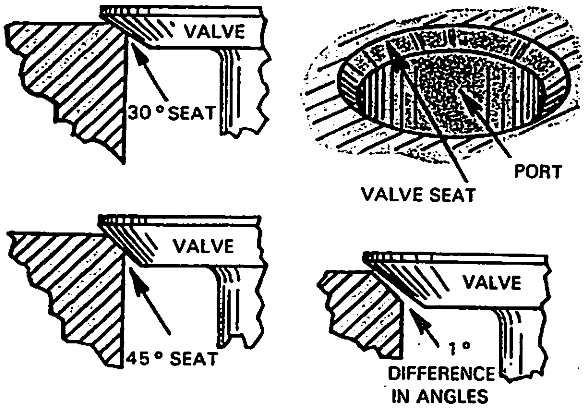


Fig. 2-74. Common valve seat angles.

head. Fig. 2-75. Seats can also be induction hardened.

The valve face and seat must make perfect contact to insure efficient operation.

VALVE GUIDES

The valve guide can be an integral part of the cylinder head; or it may be made as a separate unit, pressed into a hole in the head or block, depending on which unit contains the valves.

The pressed-in type of valve guide is made of cast iron. The valve stem must fit this guide with about .002–.003 in. (0.05–0.08 mm) clearance. Fig. 2-76.

VALVE SPRINGS

Springs push the valves closed when the cams lower. Since the springs are compressed and expanded over 70,000 times per hour at 50 mph (80.5 km/h), they must be made of high quality spring wire.

You have already learned how the spring is fastened to the valve by means of a spring washer and split keepers.

Some springs have the coils closer together at one end than at the other. In an installation of this kind, the end with the more closely spaced coils must be placed against the head, or block, whichever the case may be. Some engines use two springs per valve, one spring inside of another.

VALVE LIFTERS (Mechanical Type)

Mechanical lifters are usually made of cast iron. The bottom part that contacts the camshaft is hardened. Some lifters are hollow to reduce weight. A screw is placed in the top to adjust clearance between end of valve stem and lifter. Fig. 2-77.

VALVE LIFTERS (Hydraulic Type)

The hydraulic valve lifter performs the same job as the mechanical lifter. The major difference is that the

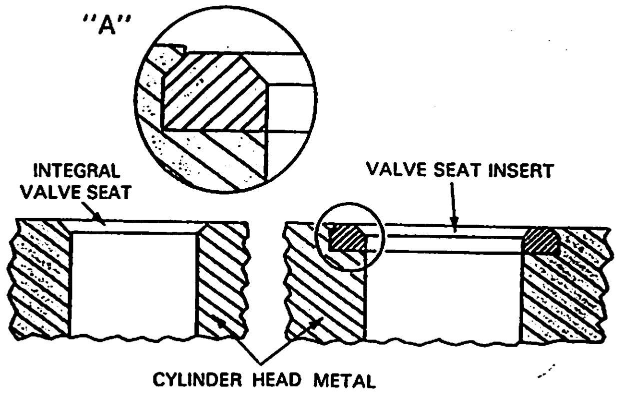


Fig. 2-75. Valve insert is often frozen to shrink diameter, then pressed into warm head to secure insert. Head metal, A, can be peened over edge of insert to aid in securing.

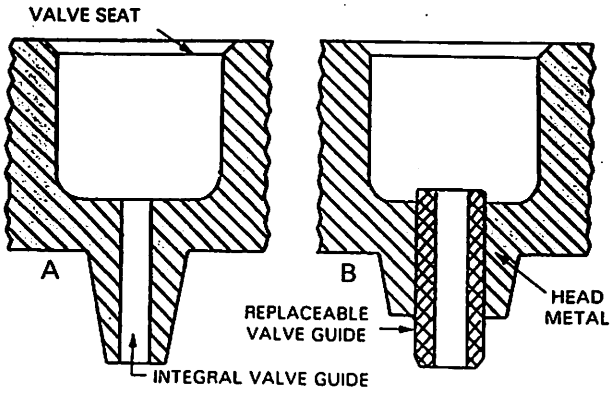


Fig. 2-76. Examples of valve guides. A–Integral (not removable). B–Pressed-in (removable).

hydraulic lifter is self-adjusting, operates with no lifter-to-rocker arm clearance, Fig. 2-78, and uses engine oil under pressure to operate. Hydraulic lifters are quiet in operation.

To operate, engine oil under pressure enters the hydraulic lifter body. The oil passes through a small opening in the bottom of an inner piston, into a cavity beneath the piston. The oil raises the piston up until it contacts the push rod (the oil pressure is not high enough to open the valve).

When the cam raises the lifter, pressure is applied to the inner piston. The piston tries to squirt the oil back through the small opening but cannot do so as a small check ball seals the opening.

As the cam raises, the lifter becomes solid and lifts the valve. When the cam lowers, the lifter will be pushed down by the push rod. The lifter will then automatically adjust to remove clearances. Fig. 2-78 shows one type of hydraulic valve lifter. See Fig. 2-79 for complete lifter action.

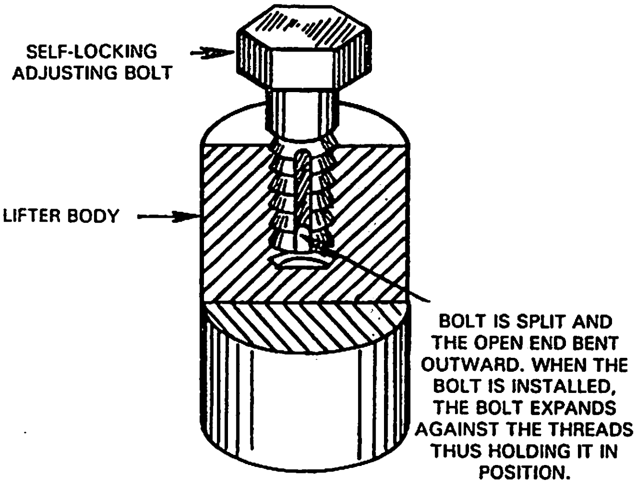


Fig. 2-77. Mechanical valve lifters usually are solid. Hollow lifters reduce weight.

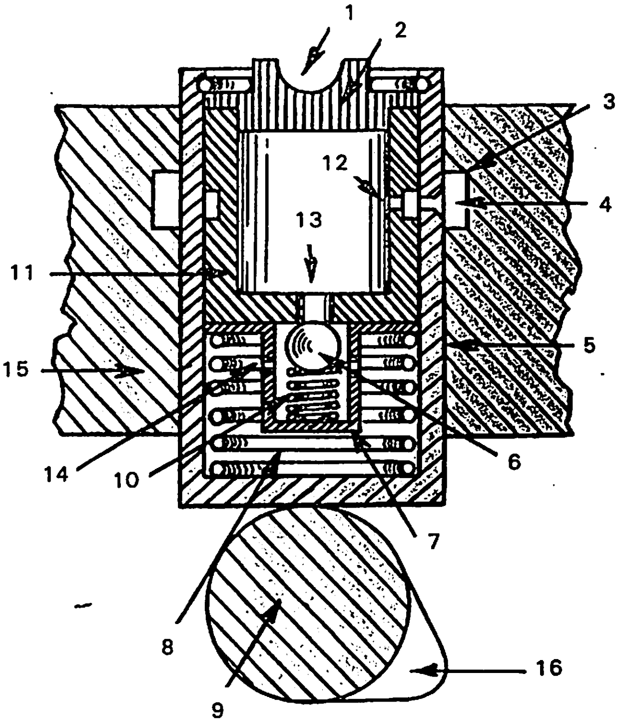


Fig. 2-78. Typical hydraulic valve lifter. Oil enters channel 3 in block, passes through hole 4 in lifter body 5, then enters hole 12 in inner piston. It fills inner piston cavity and passes through hole 13. This pressure will push check ball 6 off its seat. It now flows through hole 14 in the lifter cage 7. It fills the cavity under inner piston 11. The pressure raises inner piston up until it contacts valve push rod, or stem, whichever is used. Other parts are: 1—Push rod seat. 2—Inner piston cap. 15—Block. 8—Inner piston spring. 10—Ball check spring. 9—Camshaft. 16—Lobe.

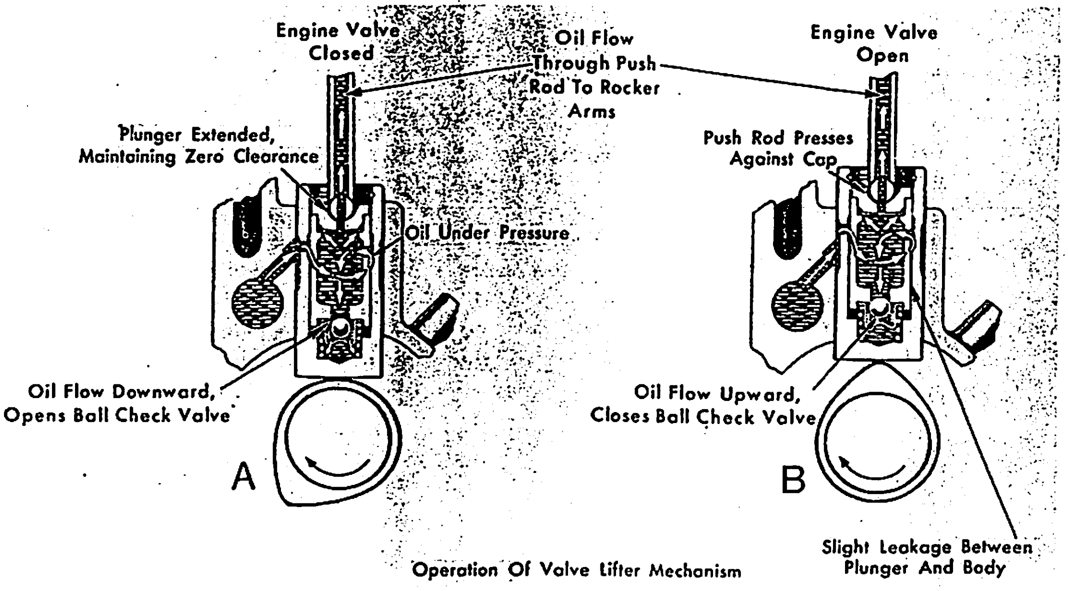


Fig. 2-79. Hydraulic valve lifter operation during two stages. A—Valve closed. B—Valve open. (Cadillac)

TURNING HELPS

If the valve goes up and comes down in the same place time after time, carbon buildup between valve face and seat may cause the valve to remain partially open. This will cause valve burning. If the valve turns even a few degrees on each opening, a wiping action between face and seat will be developed. This keeps carbon from building up.

Turning also helps to prevent localized hot spots since the valve will keep moving away from the hottest areas.

RELEASE TYPE ROTATOR

There are several methods of causing valves to rotate as they open and close. One is through the use of a release type mechanism. This removes the spring tension from the valve, while open, and induces rotation from engine vibration. See Fig. 2-80.

POSITIVE TYPE ROTATOR

An example of the positive type rotator is shown in Figs. 2-81 and 2-82. In this mechanism, when the lifter applies pressure to the valve stem or push rod, the valve spring pressure on the seating collar causes the collar to press down on the flexible washer.

The washer then presses down on the balls, causing them to roll downward in their inclined races (small grooves guide ball). This rolling action causes the retainer and the valve to turn a few degrees.

When the valve closes, lifter pressure is removed and the ball springs cause the balls to move back up the inclined races. The unit is then ready to function again.

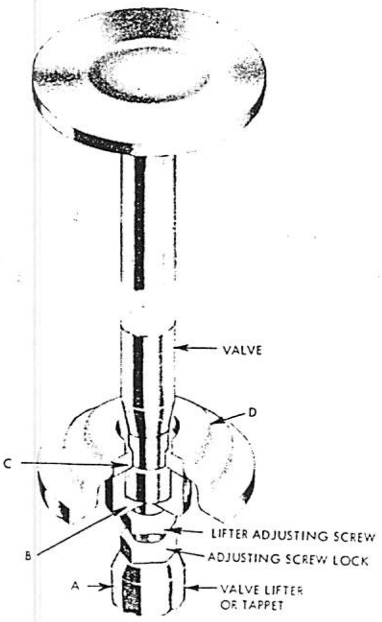


Fig. 2-80. Thompson Rotovalve—release type. (Thompson Products)

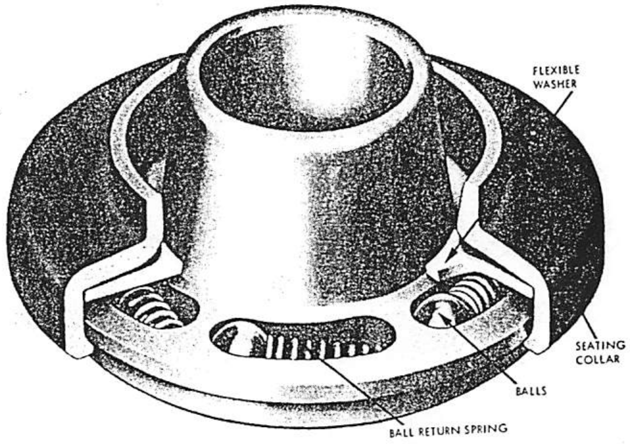


Fig. 2-81. Thompson Rotocap—positive type.

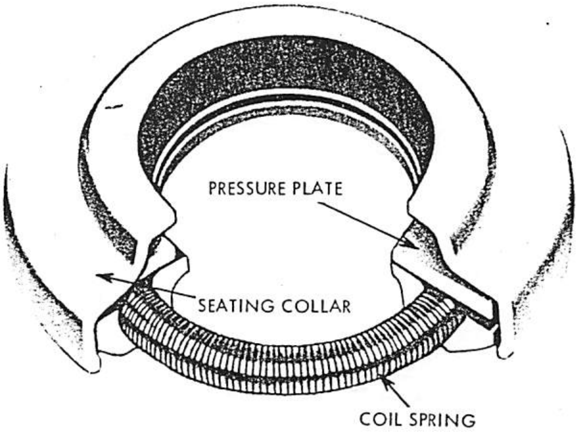


Fig. 2-82. Thompson Rotocoil—positive type.

ROLLER LIFTERS

Some heavy-duty engines, as well as those having a special camshaft, use valve lifters with rollers that contact the camshaft. The roller reduces wear on both the lifter and the cam. Fig. 2-83.

VALVE TIMING

Both the intake and exhaust valves are open longer than it takes the piston to make a stroke. The exact number of degrees that a valve will open or close before top or bottom dead center varies widely, depending on engine design. The degrees shown in Fig. 2-84 are for one specific engine. You will note that the intake valve opens about 20 deg. before the piston starts down on the intake stroke. It closes about 67 deg. after the piston reaches the bottom of its stroke.

The exhaust valve opens about 69 deg. before the piston reaches bottom dead center (BDC) on the power stroke. It does not close until about 27 deg. after top dead center (TDC) on the intake stroke.

The early opening and late closing of both valves greatly improves the intake of fresh fuel mixture and the thorough exhausting of burned gases.

The intake and exhaust valves, Fig. 2-84, are partially open at the same time. For example, the intake valve opens 20 deg. before TDC and the exhaust valve closes 27 deg. after TDC, on the same intake stroke. This situation is termed VALVE OVERLAP. It does not impair engine performance.

When a valve closes or opens, how fast it will rise, how long it will stay open, and how fast it will close depends on the shape of cam lobe and the position of the camshaft in relation to the crankshaft.

The two timing chain sprockets are generally marked to insure correct valve timing. When a line drawn through the center of both shafts bisects the timing marks, timing is correct.

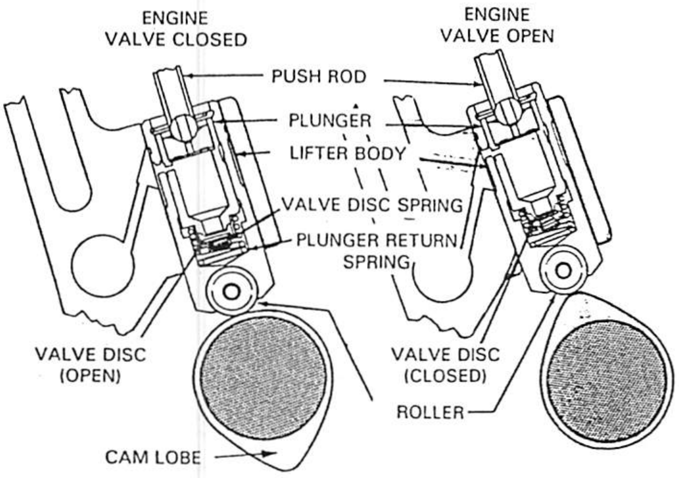


Fig. 2-83. Roller lifter is used in some heavy-duty applications.

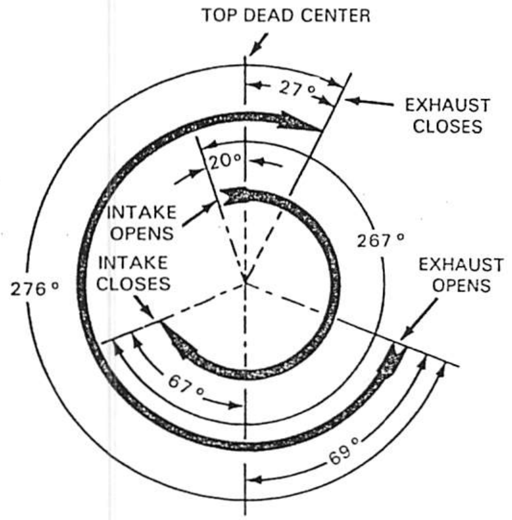


Fig. 2-84. Valve timing diagram. The angles will vary widely depending upon engine design. The length of time, in degrees, that a valve is held open is referred to as valve duration.

The camshaft is mounted to one side of the crankshaft on most in-line engines (except engines using overhead camshafts). Fig. 2-85.

On V-type engines, the camshaft is generally mounted above the crankshaft in the center region of the block. See Fig. 2-86.

Engine valves are not always operated directly from a camshaft. The valve-in-head engine utilizes additional linkage to operate the valves. This will be discussed in the chapter on engine types.

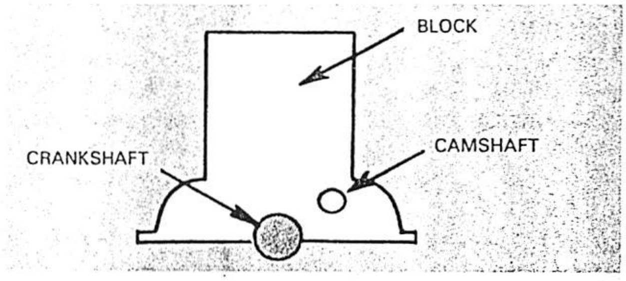


Fig. 2-85. One location for camshaft in an in-line engine. See Fig. 2-72 for cam location in an overhead camshaft, in-line engine.

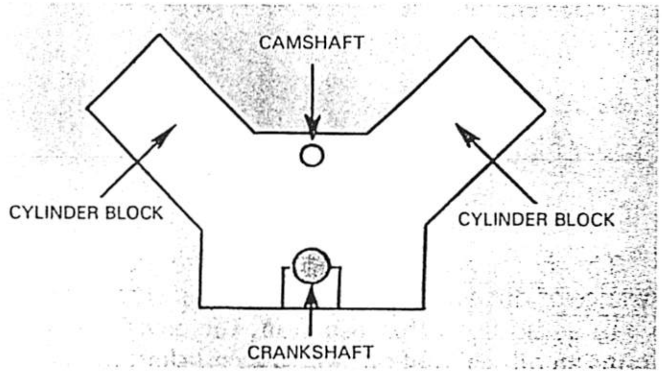


Fig. 2-86. Camshaft location in a cam-in-block or valve-in-head (OHV) V-type engine.

CYLINDER HEAD

The cylinder head serves as a cover for the cylinders and forms the top of the combustion chamber. It may contain one or both valves. The head also holds the spark plugs.

If the cylinder head contains the valves, it is called a VALVE-IN-HEAD engine.

Cylinder heads are usually made of cast iron or aluminum. They must be strong and rigid. They are bolted to the block with HEAD BOLTS.

The surfaces of the head and block that make contact must be absolutely flat. Fig. 2-87.

OIL PAN

The oil pan acts as a reservoir for oil, and it also serves as a dust shield for the bottom of the engine. It is attached to the bottom of the block with cap screws.

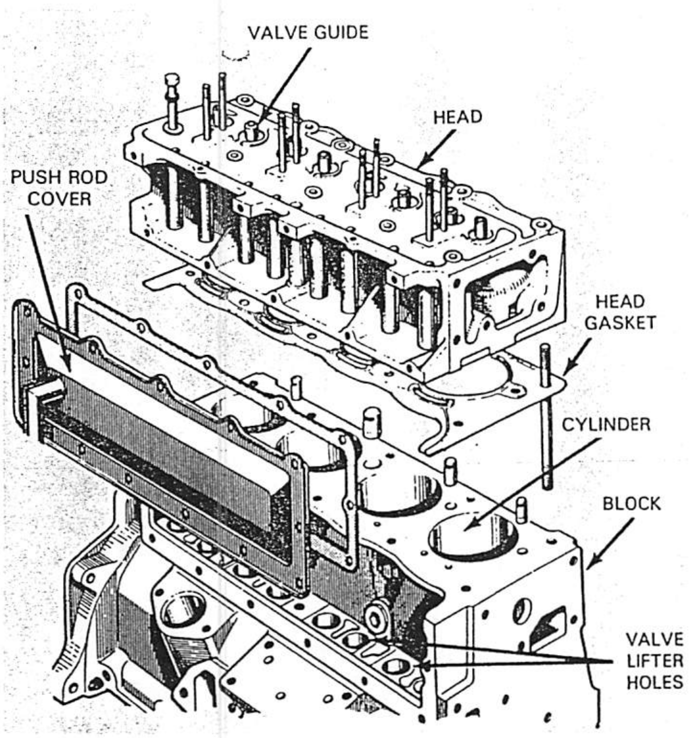


Fig. 2-87. Typical cylinder head for valve-in-head engine. Head and block surfaces must be smooth and true. (British-Leyland)

The pan is generally made of thin steel stamped to shape. Fig. 2-88. Plastics may also be used.

TIMING GEAR COVER

The timing gears must be covered to prevent the entrance of dirt and dust and to eliminate the loss of oil.

In addition to this function, the cover often contains an oil seal that allows the crankshaft to protrude through the cover and yet not leak oil.

Timing gear covers may be stamped from thin steel, or cast from aluminum or cast iron. Fig. 2-89.

GASKETS AND SEALS

In an engine where machined parts fit together, gaskets are used to make the joints tight and to prevent leakage of oil, water, and/or gasoline.

The cylinder heads must seal in the water of the cooling system and must also contain the pressure of the exploding fuel. Thin steel, copper, and asbestos gaskets are used between the head and engine block.

It is very difficult to machine metal parts to the degree of accuracy necessary for leakproof joints. As the engine expands and contracts during warmup and cooling periods, there are minute shifts in the fastened parts. This, coupled with vibration, will loosen many parts to the point of leakage.

Gasket material is somewhat resilient (soft and springy) and will adapt itself to expansion and contraction. It will also conform to irregularities in the surfaces of the mating parts. Fig. 2-90.

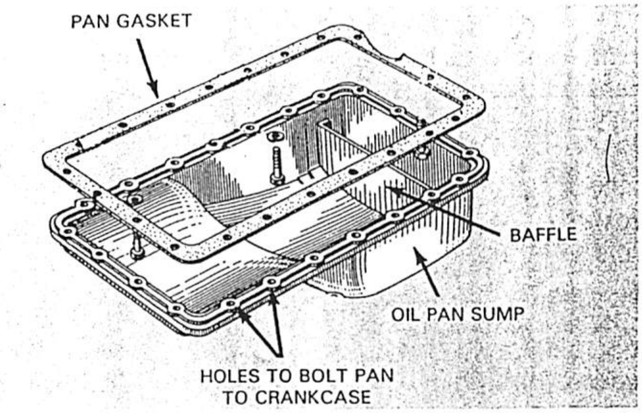


Fig. 2-88. Engine oil pan size and shape will vary widely. (Nissan)

Fig. 2-91 illustrates some of the common gaskets found in a car engine.

OTHER PARTS

Other engine parts that are required by the various systems—carburetion, ignition, lubrication, and cooling will be discussed in other sections.

In this chapter you have studied about many engine parts. A thorough understanding of design, construction and application is an absolute essential for every good auto mechanic. Go through the questions on pages 48, 49, and 50 carefully, and do not be satisfied until you can answer each and every one.

KNOW THESE TERMS

Engine block, Sleeves, Piston expansion, Piston skirt, Piston rings, Ring gap, Blow-by, Compression rings, Oil ring, Ring expander, Piston pin, Connecting rod cap, Connecting rod bearing, Main bearing, Crankshaft throw, Vibration damper, Timing sprocket, Camshaft, Valves, Valve seats, Valve springs, Valve guides, Valve lifters, Valve timing, Oil pan, Timing gear cover, Gaskets and seals.

REVIEW QUESTIONS—CHAPTER 2

Think of these questions as a special sort of scale to weigh your progress. STEP ON AND SEE HOW HEAVY YOU ARE!

1. The unit that forms a basic foundation upon which the whole engine is built is called the ____________.
2. What are cylinder sleeves?
3. The cylinders in a new engine should be glassy smooth. True or False?
4. A cylinder that is round to within .100 in. (2.54 mm) is accurate enough. True or False?
5. The main advantage of using aluminum in engine construction is that it is rustproof. True or False?
6. A piston must be ____________ and yet ____________.